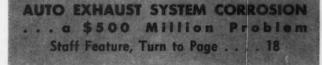
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NORTHEAST REGION—Complete program on conference. See Page 72.

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### THE SURPRISING ECONOMICS OF

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A 20' length of 6" schedule 40 carbon steel pipe weighs 398 lbs. Crane required for lifting.



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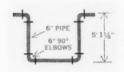
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### This Month in Corrosion Control . . .

TANTALUM, TITANIUM and ZIRCONIUM are discussed with respect to their suitability for fabrication of chemical equipment in an article beginning on Page 9. Particularly interesting are the data on hydrogen absorption characteristics and resistances to numerous corrosives. Special fabricating problems that must be solved when handling these metals are considered.

AUTOMOBILE EXHAUST SYSTEM corrosion damage in 1960 is estimated at \$500 million. A staff feature beginning on Page 18 discusses causes of exhaust system corrosion, including highly corrosive acids formed by fuel combustion in the engine, wide range of operating temperatures in mufflers, driving habits of car owners and use of dual exhaust systems. Also discussed are muffler corrosion tests, design problems in relation to corrosion and various materials being used for corrosion control purposes. These materials include zinc coated steel, aluminized steel, ceramic coated steel, chromiumrich diffusion coatings on steel and a new stainless steel specially designed for auto muffler fabrication. Tailpipe corrosion problems also are covered.

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PLASTIC PIPE and FITTINGS applicable to corrosion control work are reviewed and some significant case histories given in an article beginning on Page 30.

NON-SOLVENT EPOXY and POLYESTER based coatings are compared to solvent-dispersed types in an article beginning on Page 34. Also discussed are equipment and application procedures. Cost comparisons are made between the two systems. Chemical resistances of solvent and non-solvent coatings in immersed service are compared.

SMOG CONTROL DEVICES on automobiles could cost operators of internal combustion engined vehicles more than \$3.75 billions, assuming a minimum per vehicle installed cost of \$75 and a total of 50 million vehicles affected. An article beginning on Page 47 surveys the present state of affairs with respect to these devices, gives some information on leading types and lists some of the companies working on the problem.

UNEXPECTEDLY QUICK destruction by corrosion of copper-nickel alloy straps around wood pilings in Los Angeles Harbor has brought about an intensive study of the cause. Results of this study should interest all engineers concerned with seawater port problems. Turn to Page 83.

TANKER CORROSION and corrosion-protection data summarized from inspections of over a thousand ships are related beginning on Page 85. The principal causes of corrosion as well as an examination of the relative merits of magnesium and zinc galvanic anodes are discussed. Considerable benefits from fresh water rinsing are described. The author also discusses hydrogen evolution in ballast tanks and possible use of aluminum galvanic anodes.

SLURRY picked up by gas leaving the autoclave in a nickel refinery ammonia recovery system led to deposits of solids on wall imperfections near the cooler outlets. These deposits are cited as a principal cause of corrosion in the system in an article beginning on Page 91. Corrective measures are given. Corrosion problems encountered in other parts of the plant also are discussed.

LIQUID METAL FUEL reactors pose formidable problems in the selection of materials. Data on tests using tantalum, molybdenum and beryllium are given beginning on Page 97.

HIGH ENERGY FUEL systems which include nitrogen tetroxide require materials of high integrity because of the aggressiveness of this fluid. Beginning on Page 101 is a report of static and dynamic tests of metals and plastics exposed to nitrogen tetroxide.

SURFACES INSIDE SHIP HULLS, often subject to very aggressive corrosive conditions, usually are so difficult of access that they are seldom inspected. Various kinds of corrosion test probes that can be installed to monitor the conditions in these places of low accessibility are described beginning on Page 107. Also included are probe types designed to measure corrosion at tube ends in condensers.

STRONG AMMONIA concentrations are given as the reason for premature failure by stress corrosion cracking of admiralty exchanger tubes. Tubes removed from a reactor effluent cooler on a platinum reforming unit failed in part also because of the low sulfur content of the stream. Turn to Page 114.

CORROSIVITY OF SOIL can be estimated by investigation of the corrosion of highway culverts. An article beginning on Page 115 summarizes data obtained from examining several thousand highway culverts with respect to soil resistivity and pH. The California Division of Highways is using a statistical chart from the data to predict life of highway culverts.

CAVITATION EROSION resistance of a number of metals and plastics using a laboratory rotating disc and high speed motion pictures is examined in an article beginning on Page 119. Included are photographs of the "clouds" formed in the vicinity of a cavitation-causing perforation.

CORROSION, October, 1961

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Sulfide Stress Cracking of Steels for API N-80 Tubing Products

Use of Aluminum for Water Distillation Equipment

Effect of Redox on Refinery Corrosion

Performance of 335 Miles of Asphalt Mastic Coated Pipe Electrochemical Approach to Cavitation Damage and Prevention

Effect of Hardeners on Epoxy Resins' Chemical Resistance

Corrosion in Biological Treatment of Chemical Industry Wastes

Low Potential Zinc Anodes in Theory and Practice

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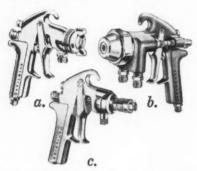
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### Where Corrosion Created A New Industry

IN THIS ISSUE a staff feature tells some of the facts about the problem of automobile exhaust system corrosion, what the problem is, how much it costs and what is being done about it. The subject of automobile muffler corrosion has been a sore one for years because mufflers corrode so fast that a whole new industry based on muffler replacement has arisen.

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As is indicated in another story in this issue, many American motorists soon will be faced with the necessity of installing on their cars a device or devices to reduce air contamination. Because some of these devices will be subjected to the same environments the rest of the exhaust system is exposed to, it is to be hoped that proper attention will be paid to the necessity for making them durable. Replacing smog-control devices probably will be a far more costly matter than replacement of a muffler and tail pipe.

The muffler corrosion problem is much like other problems faced by the consumer. Each person who has to replace a corroded muffler realizes what it costs and what additional time it takes and trouble it causes. He seldom has either the time or the inclination to think about the implications involved in the fact that hundreds of thousands of mufflers are replaced by other auto owners like himself.

The Corrosion staff, being alert to some implications of consumer corrosion troubles, could not overlook the lesson to be learned from the huge piles of replaced mufflers that may be found near every large city. These piles of discarded mufflers, exhaust pipes and resonators also represent a measure of the total problem affecting motorists everywhere.

Investigation of the causes of exhaust system damage produced some unexpected information. This included the discovery that the use of dual exhausts has the effect of increasing corrosion damage by a factor much greater than two. Also significant, from the standpoint of basic economics, was the fact that the multitude of models now offered by most major manufacturers lead to a correspondingly greater number of different exhaust designs and, consequently, a higher resulting unit cost.

When complications to the basic system (such as resonators) are added, the causes of damage become more numerous and the cost greater.

Several ingenious methods have been developed to reduce muffler damage. These involve changes in design and materials and take cognizance of the basic corrosion problem. Not all have been unqualified successes. The evidence indicates that a muffler which gives good service for a driver with one set of driving habits will give poor service for one with another. This may mean that the motorist would be wise to make a muffler selection based on his known driving habits.

This study also highlights a factor which is well known and understood already in the automobile business. This factor is the consideration of costs which, in the highly competitive field of automobile merchandising, makes pennies important. No great change for the better can be expected until the motorist understands the necessity for paying more for longer life and gives at least as much attention to the durability of his automobile as he now pays to such relatively unimportant things as superficial differences in conformation and embellishment. The manufacturer has little inducement to base his sales appeal on such undramatic things as exhaust systems as long as the potential buyer prefers to be dazzled by an irrelevant mish-mash of double talk about

When comparisons are made among passenger vehicles, even when made by impartial agencies, careful attention is paid to such things as piston travel, displacement, gear ratios, acceleration rates and the like. It can be said truthfully that none of these things are nearly as significant to the automobile owner as how often he will have to replace his exhaust system. Most automobile buyers couldn't care less about piston travel, gear ratios, turning radiuses and the like.

There are some notable exceptions to the general rule that the automobile buyer wants only to see something shiny. There are exceptions to the contention that the buyer will not be able to tolerate his car more than two or three years because it gets "out of style." There is some room for argument about whether or not the planned obsolescence implicit in the industry's practice of annual model changes is good or bad. There is not much evidence against the contention that a car's exhaust system should be made so that it will last indefinitely—or at least as long as the rest of the car.

Evidence exists that exhaust systems can be made to last longer than they now do. The consumer must recognize this fact and be willing to pay a little more to get the advantage. This could mean that a considerable part of the \$600 millions a year now being spent on replacement mufflers would be used for other, more useful purposes.

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### **Corrosion Resistance of**

### Titanium, Zirconium and Tantalum Used for Chemical Equipment\*

#### Abstract

Abstract:

Attractive properties of titanium, zirconium and tantalum for fabrication of equipment to be used in corrosive environments of the chemical industry are detailed. Relation of hydrogen absorption properties and resistance to numerous corrosives at varying temperatures are related in the text and tabulated data. Some special problems faced when these metals are fabricated are considered and solutions of come are described. Some typical examples of equipment fabricated of titanium, zirconium and tantalum are pictured. 13 references. 6.3.15, 6.3.13, 6.3.20, 8.8.1

### Clifford A. Hampel

Chemical Engineer Skokie, Illinois

A MONG the rare or less common metals which have been the subject of so much attention in recent years, tantalum, titanium and zirconium are the principal ones of great usefulness for the fabrication of corrosion resistant chemical equipment. Tantalum has been used for this purpose for many years and titanium and zirconium are being increasingly used for equipment subjected to highly corrosive exposures.

For this purpose it is not enough that a metal demonstrates superior resistance to extremely corrosive media. It also must have mechanical properties that permit it to be fabricated into the desired forms if it is to be applied widely in the chemical industry. These metals satisfy both conditions. They combine fine chemical properties with ductility, good strength, fabricability and weldability. Because all become very reactive at temperatures above a few hundred degrees Centigrade, they must be welded in inert atmospheres so they will not react with oxygen and nitrogen and become embrittled and structurally weakened. When properly handled they demonstrate no variation in corrosion resistance at welds, differing in this respect from many alloys, such as stainless steels, which are subject to selective attack in the weld area.

Table 1 gives some physical properties. Compared to steel, whose density is about 8, tantalum is twice as heavy, while titanium and zirconium are much

lighter. Tantalum has a melting point about twice that of steel and those of titanium and zirconium also are very much higher than steel's. Furthermore, the coefficient of thermal expansion of steel is much greater than that of any of the three so this must be considered in the design of equipment where steel is fastened to any of them, as in a steel shellmetal tube heat exchanger.

### Comparative Corrosion Properties

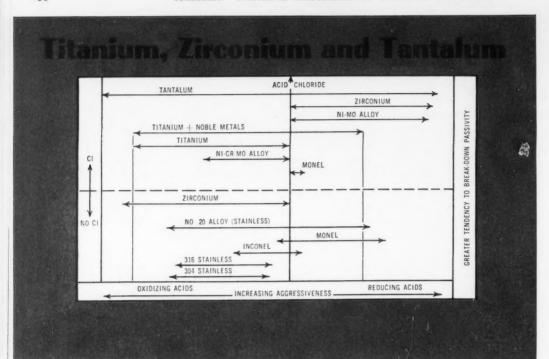
The corrosion properties of the three metals are best summarized by reference to Figure 1. The horizontal ordinate concerns oxidizing conditions on the left and reducing conditions on the right of a vertical line at the center denoting neutral, with the aggressiveness increasing with distance both directions from the center. The vertical ordinate denotes varying conditions resulting from the presence or absence of the chloride ion, the greater the distance from the horizontal the greater the tendency of passivity to breakdown.

### Tantalum

This figure shows tantalum to be the most corrosion resistant metal in both oxidizing and reducing conditions and at high chloride concentrations. Nonoxidizing or reducing agents include hydrochloric acid, sulfuric acid, phosphoric acid, oxalic acid, acetic acid, and aluminum and zinc chlorides. Oxidizing conditions include such reagents as nitric acid, ferric and cupric chlorides, aqua regia, hydrogen peroxide and hypochlorite solutions. Tantalum is attacked by

(Continued on Page 10)

<sup>\*</sup>A paper presented under the title "Corrosion Resistant Equipment of Titanium, Zirconium and Tantalum," at a meeting of Eastern Division, Canadian Region, National Association of Corrosion Engineers, at Montreal, Quebec, November 14-15, 1960.



### (Continued From Page 9)

hydrofluoric acid or acid solutions of fluorides, which also attack titanium and zirconium and by free sulfur trioxide, among acid media.

Zirconium is quite good under reducing conditions in the presence of acid chlorides and under oxidizing conditions in the absence of acid chlorides.

### Titanium

Titanium is useful only under oxidizing conditions and the chlorides do not affect it. However, the addition of as little as 0.1 palladium or some other noble metal as an alloying agent in titanium extends the region of corrosion resistance well into the reducing zone. This discovery by Stern of Union Carbide Metals Co. greatly widens the area of applicability of titanium in the chemical equipment field.<sup>2</sup> Except for enhanced corrosion resistance, the titanium-palladium alloy has the same properties as titanium.

The palladium additive concept is based upon an electrochemical theory developed by Stern which describes how passivity type corrosion inhibitors function. From this he predicted that alloying with noble metals would create a similar electrochemical situation in titanium. The platinum group additive creates galvanic couples at the surface of the alloy. These provide a mixed potential at the surface higher than the critical potential for passivity of the titanium.

### Zirconium

Zirconium has the best resistance to attack by alkaline systems, including molten sodium and potassium hydroxides. Tantalum has a very low rate of corrosion in dilute sodium hydroxide but is poor at higher concentrations. Titanium is resistant to alkaline solutions but not quite as good as zirconium.

Figure 1—Corrosion resistance of titanium, titanium alloyed with noble metals; zirconium, tantalum and other alloys is diagramed. General corrosive effects of oxidizing and reducing acids and of the chloride ion are illustrated. (Photo, Union Carbide Metals Co.)

Table 2 indicates in tabular form the corrosion ratings of tantalum, titanium, zirconium and 316 stainless steel in a variety of corrosive media. The rating of "excellent" for tantalum in the inorganic acids, organic acids and chloride solutions categories actually should be zero corrosion under all conditions. In dilute NaOH and KOH the rate of attack is not zero, but it is less than 0.5 mpy.

### (Continued on Page 12)

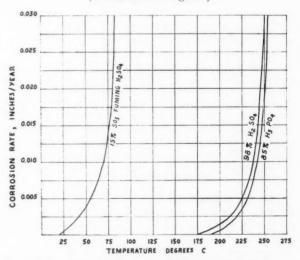


Figure 2—Corrosion rate versus temperature of tantalum in 15 percent  $SO_a$ , fuming  $H_aSO_a$ , 98 percent  $H_aSO_a$ , and 85 percent  $H_aPO_a$ .

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### Titanium **Zirconium Tantalum**

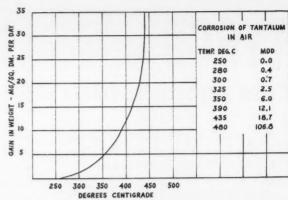


Figure 3—Corrosion of tantalum in air, expressed as weight gain mg/sq/ dm/day, versus temperature.

(Continued From Page 10)

Tantalum is inert to solutions con-taining chlorides, and titanium is either inert or is attacked at a very slow rate, but zirconium withstands chloride solutions only under reducing conditions. Thus, it is attacked in hydrochloric acid which contains cupric or ferric ions, such as might be present in a pickling bath, despite its very high resist-ance to hydrochloric acid containing no oxidizing agents. Relation of Hydrogen

Before describing some details of effects of corrosive agents on the three metals, the relation of hydrogen and the metals should be considered. Molecular hydrogen is absorbed by each metal at temperatures above about 300 C. The rate of absorption for titanium and zirconium is very much greater than is the rate for tantalum. The absorption causes embritlement of the metals due to an expansion of

With tantalum, similar embrittlement occurs at lower temperatures when atomic hydrogen is discharged on its surface, as by cathodic electrolysis or chemical attack which releases hydrogen. Titanium and zirconium apparently do not experience this effect with atomic hydrogen since corrosion of them by acids does not result in hydrogen embrittlement. Since tantalum becomes cathodic when in galvanic cell circuit with almost all metals, it must be prevented from becoming cathodic in chemical equipment lest it fail structur-

ally by the ensuing embrittlement.

Inasmuch as it is almost always de-

sirable to avoid any type of galvanic couple in chemical equipment, the practice is to design and install equipment to prevent the occurrence of such cou-ples. This practice in turn limits the danger of tantalum becoming embrittled cathodic hydrogen discharge upon its surface.

An article on prevention of hydrogen embrittlement of tantulum by discharge of atomic hydrogen on the surface of the metal was published on Pages 85-91 of the August, 1961, issue of Corrosion The co-authors of this article discovered that physically contacting tantalum with an extremely small area of platinum will prevent the hydrogen embrittlement of tantalum in aqueous media. Made by sputtering, spot welding or mechanical at-tachment, the contact does not affect the corrosion resistance of the tantalum. The ratio of areas needs to be no more than one of platinum to 10,000 of tantalum in some cases. Tantalum is embrittled in a few hours in concentrated hydrochloric acid at 190 C, but a system of the above ratios of platinum to tantalum is immune to embrittlement for more than

This important discovery may well eliminate this troublesome weakness of tantalum and will extend its scope of

usefulness,

Tantalum Among Most Inert

Tantalum is one of the most inert of all metals to reaction with chemicals at temperatures below roughly 150 C. The only reagents which attack it rapidly are fluorine, HF and free sulfur trioxide. Alkalis react with it slowly, the rate increasing with alkaline concentration and temperature rise. At higher temperatures tantalum becomes increasingly reactive with a variety of reagents, including air.

Although no attack occurs at lower temperatures, regardless of concentration, hydrochloric acid begins to corrode tantalum at elevated temperatures. Tests at 190 C have shown a corrosion rate of less than 1 mpy for concentration up to 25 percent HCl, where some embrittlement due to hydrogen occurs. The rate of attack is 3.9 mpy in 30 percent acid and 11.6 in 37 percent acid, with increasing embrittlement as the concentration increases. At this temperature the pressure

creasing embrittlement as the concentration increases. At this temperature the pressure is nearly 1000 psi for 37 percent acid.

Nitric acid at 190 C and concentrations up to 70 percent has a corrosion rate of less than 1 mpy. Other tests at temperatures of 200 C or more with a variety of UNO exceptations. temperatures of 200 C or more with a variety of HNO<sub>3</sub> concentrations have shown nil attack.<sup>4,5</sup> The presence of HCl or chlorides in the acid does not affect the resistance and tantalum is inert to boiling aqua regia.

In 98 percent sulfuric acid, a In 98 percent sulfuric acid, a slow uniform attack begins at about 175 C,6 as shown in Figure 2. At all concentrations below this temperature, there is no attack. As the temperature of 98 percent H2SO4 rises, the corrosion rate on tantalum increases rapidly: at 200 C it is 1.5 mpy, at 250 C it is 29 and at 300 C it is 342. As the concentration of the H<sub>2</sub>SO<sub>4</sub> is decreased, the rate of corrosion at a given temperature tends to become less. For example, a test in a chemical company concentrator has shown a rate of 3.1 mpy in 90 percent acid at 250 C. This is about one-tenth that for 98 percent acid at this temperature. The presence of HCl or chlorides does not alter the resistance. The above exposures have resulted in no embrittlement of the tantalum.

On the other hand, tests made at the boiling points of 80, 85 and 95 percent  $H_2SO_4$  are reported to cause some embritlement of the tantalum samples.<sup>8</sup> The respective corrosion rates and temperatures are 1.9 mpy at 202 C, 19.3 at 225 C and 192 at 290 C. At 190 C, the

(Continued on Page 14)

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### **TABLE 1—Physical Properties**

	Tantalum	Titanium	Zirconium	1030 Steel
Density, g/cc	16.6 3000	4.54 1668	6.45 1852	7.86 1530
coefficient, microin./in./°C	6.6	8.4	5.89	12
Thermal conductivity, cal/cm/sec/°C Specific heat, cal/g/°C. Modulus of elasticity.	0.13 0.0356	0.041 0.125	0.04 0.066	0.124
million psi	27	15.5	13.7	28

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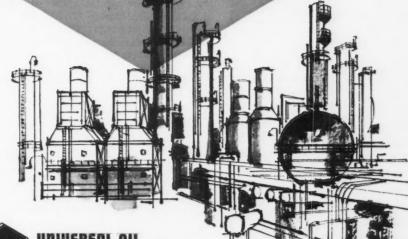
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### **Titanium**

### **Zirconium**

**Tantalum** 

(Continued From Page 12)

rate is less than 1 mpy over the whole concentration range of 5 to 95 percent

The attack of fuming sulfuric acid (containing 15 percent SO<sub>3</sub>) on tantalum is rapid. While the corrosion rate is 0.3 mpy at 23 C, it is 4 at 50 C, 9.2 at 70 C and 3900 at 130 C.6 This is shown in Figure 2. in Figure 2.

Phosphoric acid of 85 percent strength does not attack tantalum below about 130 C, but at 225 C the corrosion rate is 3.5 mpy and at 250 C is 20. See Figure 2. Another study<sup>3</sup> has reported rates of less than 1 mpy at the boiling point and at 190 C over the concentration range of 1 to 85 percent H<sub>3</sub>PO<sub>4</sub>.

### Fluoride Ion Causes Attack

If the phosphoric acid contains hydrofluoric acid or more than a few ppm of flouride ion, as frequently is the case with commercial acid, attack on the tantalum is likely to occur. By contrast, chromium plating baths containing 40 percent CrO<sub>3</sub> and 0.5 percent fluoride ion have shown nil effect upon tantalum, possibly because of complex formation between chromium and fluoride ions.

Alkalis in concentrated solutions attack tantalum even at room temperature but the metal is quite resistant to dilute solutions. In 10 percent NaOH, Tingley has found a corrosion rate of 9.3 x 10<sup>-3</sup> mpy at room temperature and in 5 and 10 percent NaOH at 100 C the rate is 0.126 mpy.<sup>6</sup>

While fluorine attacks tantalum rapidly at room temperature, the metal is totally inert to dry or wet chlorine, brototally inert to dry or wet chlorine, bro-mine and iodine below 150 C, and these elements dissolved in organic solvents or in solutions of salts or acids likewise have no effect. Dry chlorine begins to react with tantalum at about 250 C, but water vapor makes tantalum satisfacwater vapor makes tantalum satisfactorily resistant at temperatures as high as 375 C. Bromine and iodine begin to react at about 300 C, forming TaBr<sub>s</sub> and TeI<sub>s</sub>, respectively. Sulfur and hydrogen sulfide react with tantalum at red heat, forming tantalum sulfide, TaS<sub>2</sub>. Tellurium and selenium attack tantalum saterardy at about 800 C. severely at about 800 C.

When heated in air, oxygen or nitrogen, tantalum is unaffected below 250 C, is tarnished in 24 hours at 300 C and at nusned III 24 hours at 300 C and at higher temperatures the reaction rate increases rapidly. Figure 3 is a plot of rate of attack in air determined in long time exposures. No nitrides are formed in air oxidation. The reaction rate in oxygen is more rapid than in air, but slower in nitrogen? slower in nitrogen.

Tantalum reacts with CO2 CO and NO at temperatures above about 1100 C, but CO<sub>2</sub> under 8 atm pressure corrodes the metal at 500 C. Carbon, boron, silicon and phosphorus react directly with tartitum at least temperature. rectly with tantalum at elevated temperatures, to form Ta<sub>2</sub>C and TaC, TaB and TaB<sub>2</sub> and TaP and TaP<sub>2</sub>, respec-

Tantalum exhibits remarkable resistance to liquid metals at high temperatures in the absence of reactive gases (O, N, CO<sub>2</sub>, etc.). It is suitable for use

with sodium at 1200 C; potassium, sodium-potassium alloys, lithium and lead at 1000 C; bismuth at 900 C or higher; mercury at 600 C; gallium at 450 C; magnesium and uranium-magnesium and plutonium-magnesium alloys at 1150 C. It has been satisfactory for several thousand hours of service in molten metal fuel circulating loops containing magnesium-thorium alloy (37 wt% Th) magnesium-thorium alloy (37 wt% 1n) at 800 C; bismuth-uranium-manganese alloys (89.5-10-0.5 and 94.7-5-0.3 wt%) at 1160 and 1050 C, respectively; and bismuth-uranium alloys (5-10 wt% U) at

Tantalum fails in a few days when used as a container for an alloy of aluminum-thorium-uranium (76-18-6 wt%) at 1000 C, an alloy of uranium-iron (90-10 wt%) at 900 C and the eutectic alloy of uranium-chromium at

similar temperatures.

Liquid aluminum reacts with tantalum rapidly to form the stable compound, AlaTa, aluminum tantalide.

Zinc is reported to wet and attack abraded tantalum surfaces at 450 C, but an industrial zinc producer has observed corrosion resistance at 500 C.10 Maintenance of the oxide film may account for the latter result.

### Titanium Outstanding in Chlorine

Corrosion resistance of titanium is outstanding in moist (more than 50 ppm water) chlorine-containing atmospheres; chloride solutions, including those containing chlorine; hypochlorites, hypochlorons acid, chlorine monoxide and chlorine dioxide; nitric acid from 35 to 65 percent up to 265 F; aqua regia and atmospheres containing chlorine and hydrochloric acid. In dry chlorine the (Continued on Page 16)

### **TABLE 2—Comparative Corrosion Properties** of Titanium, Zirconium, and Tantalum

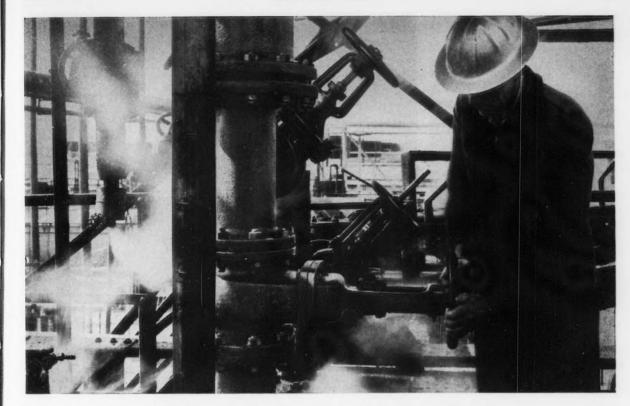
		mpy
Rating System:	Excellent	 0.5
0 -2	Good	 0.5 to 5.0
	Fair	 5.0 to 10.0

Reagent	Conc.	Temp. °F	Corrosion Ratings			
			Zirconium	Titanium	Tantalum	
INORGANIC ACIDS						
Aqua regia		65 140	Poor Poor	Excellent Excellent	Excellent Excellent	
Chromic	Dilute Conc.	Boiling Boiling	Excellent Excellent	Good	Excellent Excellent	
Hydrochloric	Dilute Conc. Conc.	All Room Boiling	Excellent Excellent Poor	Fair Poor Poor	Excellent Excellent Excellent	
Nitric	Dilute Dilute Conc.	65 212 212	Excellent Excellent Excellent	Excellent Good Good	Excellent Excellent Excellent	
Phosphoric:	Dilute Dilute Conc. Conc. Conc.	Room 212 Room 212 410	Excellent Good Fair Fair Poor	Excellent Poor Poor Poor Poor	Excellent Excellent Excellent Excellent Good	
Sulfuric	Dilute Dilute Dilute Conc. Conc. Conc.	65 95 212 65 212 570	Excellent Excellent Excellent Good Poor Poor	Good Good Poor Poor Poor	Excellent Excellent Excellent Excellent Excellent Poor	
ORGANIC ACIDS						
Acetic	Conc.	Boiling	Excellent	Excellent	Excellent	
Formic	Dilute Conc.	Boiling Boiling	Excellent Excellent	Fair Poor	Excellent Excellent	
Lactic	Dilute Conc.	Boiling Boiling	Excellent Excellent	Excellent Excellent	Excellent Excellent	
Oxalic	Dilute Conc.	Boiling Boiling	Excellent Excellent	Fair Poor	Excellent Excellent	
CHLORIDE SOLUTIONS						
AlCla CuClt FeCla. HgCl2. NaCl. SnCl4.	Satd 10% 10% Satd Satd 24%	Boiling Boiling Boiling Boiling Boiling Boiling	Excellent Poor Poor Excellent Excellent Excellent	Excellent Excellent Excellent Excellent Excellent Excellent	Excellent Excellent Excellent Excellent Excellent Excellent Excellent	
ALKALINE SOLUTIONS AND F	USED ALK	ALIS				
Molten KOH Molten NaOH	*****	******	Good Excellent	Poor	Poor Poor	
кон	5-10% 5-10% 40% 40%	Room Boiling Room Boiling	Excellent Excellent Excellent Excellent	Excellent Excellent	Excellent Fair Poor Poor	
NaOH	5-10% 5-10% 40% 40%	Room Boiling Room Boiling	Excellent Excellent Excellent Excellent	Excellent Good Excellent Good	Excellent Excellent Poor Poor	

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## 30% nickel stainless valve holds off sulfuric acid 14 months

### Outlasts others by better than 2 to 1

Handling enough hot sulfuric acid sludge to ruin at least two ordinary valves, this Crane gate valve needed only minor repairs after 14 months. Other valves lasted six months... some only three. Here is what helped make the difference:

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The design of the valve incorporates a special split-wedge disc construction. This minimizes the possibility of galling, reduces wear on

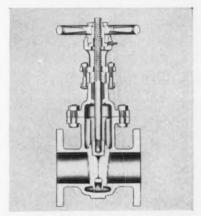
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### INCO NICKEL

NICKEL MAKES ALLOYS PERFORM BETTER LONGER

### Titanium

### **Zirconium**

### **Tantalum**

(Continued From Page 14)

metal fails rapidly, apparently by ignition. Most of these observations have been made by Gegner and Wilson in their extensive, long term exposure tests in chemical plants."

Titanium is corroded by hydrofluoric, hydrochloric, sulfuric, phosphoric, formic and oxalic acids, except that it formic and oxalic acids, except that it is resistant to quite dilute (1 percent or so) hydrochloric and sulfuric acids. However, titanium exposed to chlorine-saturated sulfuric acid solutions ranging from 40 to 60 percent at room tempera-tures suffers nil corrosion and is resist-ant to 45 percent H<sub>2</sub>SO<sub>4</sub> at 105 F in the presence of sodium chromate, sodium sulfate and chromic sufate.<sup>11</sup> Nitric acid, or ferric or cupric ions also passivate ti-tanium in sulfuric acid and in hydro-chloric acid, so that it becomes fairly resistant to more than dilute concentrations.

Titanium has excellent resistance to alkali solutions.11 It is completely resistant to potassium hydroxide at 13 and 50 percent concentrations and in sodium hydroxide is very resistant to solutions ranging from 10 percent at 180 F to 73 percent at 240 F.

While titanium exhibits very low corrosion rates in nitric acid in all concentrations above 35 percent, several exposures in anhydrous red fuming nitric acid have resulted in an explosive pyrophoric reaction caused by the reaction product. This hazard does not exist in acid containing more than 1.5 percent

Titanium probably will be most widely applied in the chemical industry in the production, handling and use of chlorine and chlorine compounds when water is present. No other metal or alloy, except tantalum, is as satisfactory in such equipment as chlorine cells which contain chlorinated brine; chlorine ducts where wet chlorine is carried; chlorinathe chlorination of sodium and calcium hydroxides to make hypochlorites; pulp bleaching systems using such agents as hypochlorous acid, hyprochlorites and chlorine dioxide; and platinum-plated titanium chlorine cell anodes.

It has proved most satisfactory in the Moa Bay, Cuba nickel plant in the han-dling of the sulfuric acid leach solution under elevated temperatures and pres-sures. About 7 tons of titanium pipe and valves are installed in this plant. Titanium has also been used in the processing of nitric acid in a variety of ways, and in the handling of chromic acid solutions.

### Zirconium vs Hydrochloric Acid

Zirconium exhibits outstanding resistance to hydrochloric acid of ail concentrations at room temperature, and to concentrations up to 20 percent at the boiling point. However, ferric or cupric ions accelerate the corrosion rate. It has excellent resistance to nitric acid in concentrations up to 70 percent and temperatures to 400 F. Where aqua

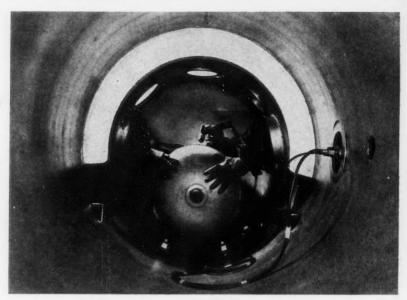


Figure 4—Inert atmosphere welding chamber for fabrication of equipment from titanium, zirconium and tantalum (Pfaudler Co. photo).

regia attacks zirconium rapidly, it is completely resistant to chromic acid.

Phosphoric acid at concentrations greater than 80 percent corrodes zirconium at 95 F, and as the temperature rises the rate of attack is inversely proportioned to the concentration. Pitting becomes severe in 60 percent H<sub>3</sub>PO<sub>4</sub> at above 60 C.<sup>1</sup>
In sulfuric acid the corrosion rate is

less than 1 mpy in 75 percent acid at 35 C, in 72.5 percent acid at 60 C and in 70 percent acid at 100 C. At higher temperatures at each concentration the corrosion rate is higher, for example, less than 5 mpy in 70 percent acid at 150 C.

Zirconium is corroded severely by wet chlorine gas, water, brine, weak hydrochloric acid and sea water which contain chlorine. It has low corrosion rates in hypochlorites, but suffers pitting. In contrast it is very resistant to dry chlorine. While it is resistant to most chloride solutions, it is attacked by ferric and cupric chlorides at concentrations above about one percent.

Among the organic acids trichloro-acetic appears to be the only one corrosive to zirconium.

### Equipment Fabrication

Resistance of zirconium to alkalis is outstanding at all concentrations and over a wide temperature range. It can be used for caustic fusions and laboratory crucibles are available for this pur-The resistance of zirconium to both acids and alkalis makes it very useful in chemical operations where there are alternate exposures to acid and alkaline conditions.

Four major problems affect the design and fabrication of chemical equipment of these metals:

1. High cost, which in sheet form is about \$50/lb for tantalum, \$7 to 13/lb for titanium and \$16 to 31/lb for zirconium, demands the use of the thinnest possible gauge for a given application.

2. Great reactivity with air, oxygen, nitrogen and carbon, generally with deleterious effects, requires the use of inert atmosphere are welding techniques, which in turn require special and expensive apparatus and operations.

3. Inability to weld to low cost metals such as steel without forming weak or brittle joints which also contain weld alloys of drastically lowered corrosion resistance, limits their combination with

low-cost metals in equipment.

4. Much lower thermal expansion compared to that of the more common

metals, must be considered when designing items incorporating both types.

All three metals can be formed by processes not drastically different from those used in most shops for other metals although zirconium and titanium are best formed hot (600 to 900 F) to prevent springback and machining op-erations require special conditions to prevent galling.

Welding has been the chief problem

involved in fabrication. It has been determined that tungsten are welding in an inert atmosphere that protects both sides being welded is the best method for obtaining uncontaminated welds that are as ductile and corrosion resist-ant as the parent metal.

In general, two methods are used to attain and maintain the inert atmosphere

1. A flow purge chamber can be constructed over the area to be welded so that both sides of the metal can be flooded with the inert gas, helium or argon, during the welding and cooling

2. A vacuum chamber into which the work is loaded is first evacuated and then backfilled with the inert gas. The welding is done by working through rubber gloves that extend into the chamber, as shown in Figure 4, a photochamber, as shown in Figure 4, a photo-graph taken through the opened end of the large chamber. While the use of trailing and leading shields with ma-chine welding equipment has been prac-ticed on titanium and zirconium, it is not recommended for tantalum. With the exception of a limited num-ber of titanium and zirconium valves and

pump components which have been

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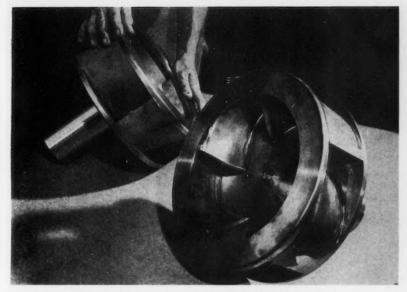


Figure 5-Titanium pachuka pump impellers. (Pfaudler Co. photo)

made by casting and machining techniques, almost all chemical equipment fabricated from the three metals has been based on the use sheet metal and thin wall tubing made from sheet metal. These forms have been used to con-struct such items as lined tanks, tube and shell heat exchangers, spiral and U-coils, bayonet heaters and condensers for a wide variety of applications. One type of equipment and its design features can be seen in Figure 5, which illustrates two titanium pachuka pump impellers, the one on the left a casting and the one on the left a casting and the one on the right a welded assembly, as can be seen by the weld beads at the base of the curved blades. Pump impellers and valve bodies also have been made of cast zirconium for commercial use in handling corrosive acids.

Figure 6 shows an all-zirconium, sinche shall rectangular tank. A horizontal

gle shell rectangular tank. A horizontal zirconium stiffening rib has been welded to the outer wall of the tank and vertical zirconium guide ribs have been welded to the inner end walls.

What is probably the largest tantalum lined vessel yet built is shown in Figure 7. This 275-gallon vessel is to be used in a pharamceutical plant and contains four separate 5-tube bayonet heaters. Inside each tantalum bayonet tube is a smaller steel tube, which extends to an outer steam chest from which steam is admitted to the tantalum tube, steam is admitted to the tantalum tube, where it condenses as it heats the vessel contents. As with titanium and zirconium linings, the lining is not bonded to the shell and extends over the flanges. The bayonets are part of the bottom closure and both top and bottom of the vessel are tantalum lined.

#### Prospect In Future

Despite their relatively high initial cost, equipment items of tantalum, titanium and zirconium will find increasing application in the chemical industry They are used now and probably will continue to be used in strategic loca-tions where their valuable and unique corrosion resistance coupled with their superior physical, mechanical and heat transfer properties enable them to replace or augment less attractive materials. This is especially true with respect to nonmetallic materials whose corro-sion resistance is good, but whose phys-

The three metals are of economic advantage in decreasing maintenance, replacement and lost production charges; minimizing contamination of products; and in providing better heat trans-fer rates than do most non-metallic materials of equivalent corrosion resistance.

The cost of equipment fabricated of them will steadily decrease as the cost of the metals themselves becomes less and as improved and more economical fabrication methods are used. Both trends have been evident in recent years and there is every reason to believe they will continue.

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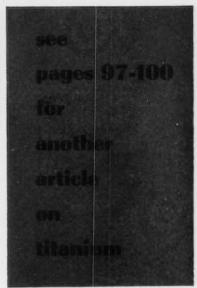




Figure 6-All-zirconium rectangular tank. (Pfaudler Co. photo)

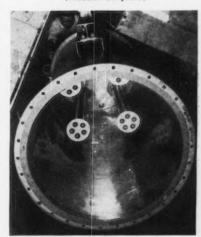


Figure 7-Titanium-lined 275 gallon reactor equipped with four 5-tube bayonet heaters extending upward from bottom closure. (Pfaudler Co. photo.)

# **Corrosion Damage on**

### \$500 Million Spent for Replacements in 1960

### Staff Feature

#### Abstract

Abstract

Discusses corrosion problems related to automobile exhaust systems. Losses to corrosion on auto exhaust systems are estimated at 500 million dollars for 1960 alone. Describes in detail following causes of exhaust system corrosion: highly corrosive acids formed by fuel combustion in engine, wide range of operating temperatures in mufflers, driving habits of car owner and use of dual exhaust system.

Discusses typical muffler corrosion test involving a corrosion box with acid condensate from engine exhaust. This laboratory evalution of materials is followed by durability field test in which prototype mufflers are installed on cars to obtain performance data.

Muffler design problems in relation to corrosion of exhaust system also are discussed. Included are high temperature design, elimination of cold spots, interchamber drainage, elimination of dual systems and change in muffler location. Discusses various materials used in Mufflers for corrosion control, including zinc coated steel, aluminized steel, ceramic coated steel, aluminized steel, ceramic coatings on steel and a new stainless steel specially designed for auto muffler fabrication.

Brief section on tailpipe corrosion problems includes data on phosphate oil Muffler design problems in relation to

mumer tabrication.

Brief section on tailpipe corrosion problems includes data on phosphate oil solution used by manufacturers to prevent rust on tailpipes during shipping and storage.

8.9.2

ORROSION DAMAGE TO automobile exhaust systems cost the American car owner over \$500 million in 1960, according to figures released by the U.S. Bureau of Commerce. There were 30 million mufflers sold in 1960 at an average retail price of \$12.50 for a total of \$375 million. About 35 million tailpipes were sold the same year at an average retail price of \$5 for a total of \$175 million-a grand total of \$500 million.

This loss to corrosion on auto mufflers alone (\$375) million) equals the total cost to the United States for construction of the Panama Canal.

Why is so much corrosion tolerated when the science and technology of corrosion control have been so highly developed?

Causes of corrosion in automobile exhaust systems have been determined, and automotive engineers know what materials and design factors can be used to minimize this costly corrosion problem. Because corrosion control measures would add a few dollars to the cost of the American auto, Detroit seems to believe that the American car buyer is not willing to pay a few extra dollars for a muffler and tailpipe that would last years instead of just a few months. American car buyers apparently are not concerned with the exhaust system on their cars until mufflers or tailpipes begin to drag underneath the car-when replacement is necessary at \$500 million in one year.

### Causes of Exhaust Corrosion

Most automobile exhaust system corrosion results from the following causes: highly corrosive acids formed by fuel combustion, wide range of operating temperatures in mufflers as determined by driving habits of the car owner and use of dual exhaust systems.

Highly Corrosive Acids

Basic cause for the devastating corrosion attack inside auto mufflers is the highly corrosive acids formed by combustion of gasoline in the engine.

In normal combustion of gasolines, acids are formed which are very corrosive to ferrous metals. These acids include sulfuric and sulfurous acids derived from the sulfur content of the gasoline and from fuel additives. Most fuels contain tetra-ethyllead, which has been increased in recent years because of the premium gasoline required for high compression engines.

The lead which is freed when tetra-ethyl-lead is burned must be volatilized so that it does not deposit on engine parts. Ethylene dibromide is added as a scavenging agent for the lead. A portion of the bromine ends up as hydrogen bromide, hydrobromic acid. Any organic chlorides in the fuel result in formation of hydrogen chloride, hydrocholric acid.

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Variations in seasonal changes made in gasolines across the country also affect production of combustion acids in the engine. Other differences are caused by the method of producing the motor fuel from crude oil.<sup>2</sup>

All these acids, varying from season to season and from one brand or grade gasoline to another, are blown into the auto muffler to create a highly corrosive environment. Engineers estimate that this muffler environment is supplied with more than a gallon of acid impregnated water in vapor form for each gallon of gasoline burned in the average auto engine.<sup>3</sup>

Operating Temperatures and Driving Habits

The auto exhaust system has a constantly freshened acidic environment with a pH of about 2.5—quite a corrosion problem. And this problem is complicated further by the wide range of temperatures in the muffler and by the variety of driving habits among car owners.

Muffler temperatures fluctuate from the obvious ambient temperatures (which can be down to zero degrees) to 1300 F in some parts of the muffler. This problem is still further complicated by the fact that some muffler parts reach the higher temperatures faster than other parts.<sup>1</sup>

Because failed mufflers show that centain portions were destroyed by corrosion faster than others, tests were conducted to determine what temperature ranges were most corrosive to the muffler. Results indicated that peaks in corrosion rates occur at 180 F and 900 F. Because most muffler parts in normal passenger car service do not reach 900 F except during long term, high speed driving, detailed studies were made of the 180-degree corrosion peak.

This 180-degree temperature is approximately the condensation point of muffler acid condensate. Thus, the highest corrosion rate occurs at about the same temperature that the condensate vaporizes. At temperatures above 180 F, the condensate is vaporized and blown from the muffler, making little contact with the metal, explaining the lower corrosion rates at temperatures just above 180 F.

Examination of corroded mufflers has shown that parts exposed longest to the high corrosion temperature range failed and that the failed parts were the same in cars operated by drivers with similar driving habits. When cars are driven for long periods, all muffler parts reach a steady state of temperature generally above 180 F, thus vaporizing most exhaust acids, blowing them from the system and consequently lowering the corrosion rate.

Obviously, the muffler temperature problem is closely related to the driving habits of the car owner. If short runs are made frequently, for example, some muffler parts can reach high temperatures while other parts remain at lower temperatures. During typical start-stop driving, some sections of the muffler are held in the highly corrosive temperature range for longer periods.<sup>2</sup>

High speed turnpike driving can push muffler temperatures to 1100 F, above the two temperature ranges at which high corrosion rates occur. Steady highway driving at 60 mph usually results in muffler temperatures just above 850 F.4

Thus, the automobile that is driven for long periods at a time has less muffler corrosion; the car driven more frequently on short runs has the worst corrosion problem.

Most corrosion attack on auto mufflers is internal. However, in geographic areas where de-icing salts are used during winter months, some corrosion does occur on external surfaces of mufflers and tailpipes. This probably is no more than 5 to 10 percent of total muffler corrosion even under the worst winter conditions.<sup>2</sup>

#### Use of Dual Exhaust Systems

Beginning about 1955, auto designers started the engine horsepower race that added more problems in respect to muffler corrosion. The higher horsepower engines required special premium fuels with higher lead content, thus increasing the volume of corrosive acids in the exhaust condensate. And, ironically, these more powerful engines had cooler exhaust gases than earlier engines because of improved cooling systems, especially the larger water jackets which reduced the temperatures of exhaust gases. Consequently, cooler exhaust gases in the newer engines condensed in the muffler more easily.

in the muffler more easily.\*

This horsepower race among American car manufacturers fostered a major cause of increased muffler and tailpipe corrosion—the dual exhaust system.\*

Because engines operate more efficiently if exhaust back-pressure on valves is reduced, dual exhausts became standard equipment on most American cars with V-8 engines. The V-8 engine with its two banks of cylinders seemed designed for dual exhausts.

Because dual systems were designed primarily to relieve exhaust back-pressure and improve engine efficiency, no provision was made to reduce muffler size despite the fact that each muffler in a dual system probably would be handling only half as much exhaust fumes as a single muffler system on the

same engine.

One result of dual systems used so widely on American cars from 1955 to current models was that muffler life was cut in half. The reason: each muffler in a dual system operates at lower temperatures than a single muffler would on the same car; therefore the corrosive condensate from the engine remains in the muffler for longer periods. Dual system mufflers also take longer to reach temperatures high enough to vaporize acids and to permit them to be blown from the system. Consequently, both mufflers in a dual system generally remain at the low temperature, high corrosion state much longer than a single muffler. Typical start-stop driving in cities lowered service life on some dual systems to six months or less.

This low heat problem in a dual sys-

This low heat problem in a dual system was aggravated by the heat control valve usually installed on one side or other of a dual system. During short runs, this valve tends to keep one side of the system in a lower temperature range for longer periods than the other side. This explains the strange failure of one muffler in a dual system before the other although to the average car

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\*In this article, components of the exhaust system will be referred to as follows: "exhaust pipe" that connects engine manifolds to muffler, "tailpipe" that extends from muffler to rear of automobile where exhaust is blown out.

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owner it seemed logical that both muf-flers should give equal service. In studying the corrosion character-istics of mufflers, one company found that single system mufflers tended to have corrosion failures at locations which could be predicted though not necessarily at the same location in all applications. These single systems also tended to have definite service life expectancies. These expectancies, however, could not be applied to dual systems because corrosion occurred at random places on internal surfaces of the muffler. Service life of dual mufflers tended to be determined primarily by the driv-

An interesting sidelight to the dual muffler system era of the past five or six years is the extreme complexity of systems used on American cars. For example, all models of Ford cars for the years 1935 through 1938 required the years 1935 through 1938 required only one muffler, one tailpipe and two exhaust pipes for replacements. In other words, only four different exhaust systems for all the different models designed during those four years. But Ford cars from 1955 to 1958 had 17 different mufflers, 45 tailpipes and 25 exhaust pipes—a total of 87 different exhaust systems. Auto parts dealers and muffler re-

Auto parts dealers and muffler re-placement shops had a serious inventory placement shops had a serious inventory problem in attempting to stock the many components needed for all these complex exhaust systems. Automobile engineers added even more problems by including resonators on many models. Thus many cars had dual exhaust systems with four mufflers in addition to the usual exhaust pipe and tailpipes. (See Figure 1 for an example of this complex exhaust system) Replacement complex exhaust system.) Replacement of some typical complex dual exhaust systems including resonators cost the car owner over one hundred dollars.<sup>5</sup>

### Muffler Corrosion Tests

The obvious need for materials to resist the severe corrosion conditions inside the auto muffler, accompanied by a chorus of complaints by car owners, spurred muffler manufacturers into test ing various materials to find some with better corrosion resistance for extended muffler service life.

Like any other corrosion test, muffler corrosion tests had to be made over a sufficient length of time if reliable data were to be obtained. Although accelerated tests were used, results had to be verified by auto service tests. Ultimately, installing test mufflers on automobiles driven by "typical" drivers is about the only sure method to evaluate new materials and muffler design. This procedure

obviously takes years.<sup>6</sup>
One company which supplies hot dipped aluminum coated steel for mufflers has distributed test mufflers for installation on autos in various parts of the country. Tags attached to these mufflers instruct the garage mechanic and car owner to return the failed muf-fler to the company's engineering de-partment. (See Figure 2.) Metal tags on these test units even stipulate that the car owner will receive five dollars for returning the test muffler with date replacement and speedometer reading.

Importance of corrosion tests of auto Importance of corrosion tests of auto mufflers is indicated by the refusal of several companies to release test data for publication. Of the 17 muffler manufacturers who were asked to submit information for this article, several ignored the request, but more signifi-

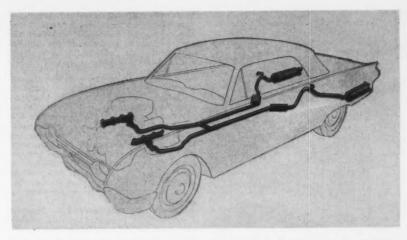


Figure 1—Complexity of dual exhaust systems is illustrated by this system on the 1961 Ford Thunderbird. Included are two-piece exhaust pipes on each side from the exhaust manifolds on the engine, two resonators, an intermediate exhaust pipe on each side behind the resonators, the two mufflers and two short tailpipes.

cantly, others replied to the effect that they considered their corrosion tests data to be confidential. (See special insert on Page 27, listing companies which submitted data for this feature.)

A test procedure that probably is typical of the muffler industry is conducted by Arvin Industries, Inc., of Columbus, Ind., manufacturer of automufflers for original equipment and replacements. placements.

The Arvin muffler corrosion test in-volves a preliminary accelerated labora-tory evaluation followed by durability tests on cars.

Laboratory Evaluation Test

Arvin uses a corrosion test box which is a sealed unit filled with condensed exhaust fumes obtained by burning fuel in an engine. The box is maintained continuously at 186 F. Because motor fuels vary from one season to the next, control coupons of known materials are used to check the corrosion box results. This corrosion box test usually takes 600 to 800 hours to evaluate the materials to destruction or to destruction of some known materials.<sup>2</sup>

Test panels used are 2 by 6-inch, 20-gage coupons of the materials being evaluated. Time-to-failure may range from 600 to 1500 hours. Failure is considered to 1500 hours. sidered to occur when a hole in the test panel is about one quarter of an inch in diameter. Pinholes are not considered.

Durability Field Test

After the laboratory corrosion box test, prototype mufflers are fabricated of materials that showed promise of good performance for service conditions on These mufflers are installed on autos in various geographic areas. Accurate records maintained on the cars include information on the operator's driving habits, fuel used, mileage and other pertinent data.

After one year, the test muffers are

other pertinent data.

After one year, the test mufflers are carefully evaluated. This evaluation is compared with those on other mufflers in various geographic areas, but only on cars for which the mileage, fuel type and operator driving habits are known.

Arvin considers this one-year dura-bility test sufficient to indicate which

materials are best for use in mufflers for corrosion resistance.

Muffler Design Problems

Muffler Design Problems

Certain aspects of muffler designing and engineering can be used to help control corrosion of this vulnerable automobile part. However, designing to control corrosion must be a secondary concern of the engineer because the muffler must be designed first as a sound muffling device—regardless of the corrosion problem encountered.

Unless the car owner is willing to tolerate the rumbling, hot rod sound of the glass-packed mufflers that have essentially no chambers, he must purchase

sentially no chambers, he must purchase a muffler that has several baffles, head-ers, tubes and chambers—all designed

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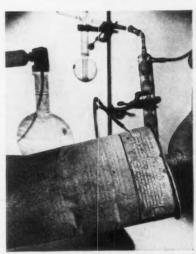


Figure 2-Test mufflers with metal identification tags attached have been used by manufacturers to obtain performance data on automobile service. The metal tag includes an identification number, instructions to the mechanic to give the muffler to the car owner and instructions to the owner to return the muffler to the manufacturer for a five-dollar award. Date of replacement and speedometer mileage are requested.

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to silence the car engine's roar—but also factors that create many corrosion problems.

Therefore, any design for corrosion control purposes must not alter the design for silencing purposes.

### High Temperature Design

One design method to control muffler corrosion is to build the unit to operate at a temperature higher than normal. Asbestos wrapping is the most common material used for this purpose. Several manufacturers build mufflers with inner and outer shells of steel, sandwiching a layer of asbestos between the shells to retain heat inside, as illustrated in Figure 3. If heat can be held inside, chances are better for the muffler operating uniformly at temperatures above the vaporization point of the acid condensate. Thus the vapor can be blown from the muffler, thereby lowering the corrosion rate and shortening the exposure time to the acids.

However, the asbestos between metal shells of a muffler can become a factor that will shorten the unit's service life. When the inner shell is perforated by corrosion (which can occur within a few months), the asbestos sheeting acts as a blotter, absorbing and retaining the exhaust fume corrodents. Thus the as-

bestos, initially designed to help stop corrosion, can accelerate corrosion of the outer and inner shells. When the outer shell is perforated, the muffler becomes noisy and should be replaced because of the carbon monoxide hazard to car passengers.

### Elimination of Cold Spots

Design also can be used to eliminate potential cold spots in a muffler where exhaust acids would remain in the low temperature range and thus cause higher corrosion rates. One company has redesigned its muffler so that the corrosive acid condensate does not remain in the cold spots. A system of venting baffles has been designed to divert the condensate back over hot spots in the muffler tubes for fast vaporization.<sup>5</sup>

Another manufacturer has designed a muffler with longer tubes to distribute the heat more uniformly inside the muffler to eliminate cold spots. This manufacturer markets a muffler to fit 1954-56 Ford cars, for example, which has a total of 80 inches of tubes. Three other manufacturers' mufflers for the same model cars have only 47, 49 and 53 inches of tubes. These longer tubes also are designed to give quieter operation and less back pressure on the engine.

#### Interchamber Drainage

Still another design factor that some manufacturers are using to control corrosion is drainage holes between the muffler's two or three chambers. These holes are designed to permit the acid condensate to flow from one chamber to the next for better vaporization and lowered corrosion rates. Figure 4 shows dramatic comparison of mufflers with and without these interchamber drains and the effect on service life of these holes.

### Elimination of Dual Systems

Despite the evidence that dual exhaust systems are possibly the main reason for shortened muffler life because of corrosion failures, American auto designers have not shown any significant tendency to eliminate the dual system. According to showroom literature, for example, the 1961 Chrysler Imperial still has dual exhaust systems with two mufflers and two resonators. Both the

1961 Lincoln Continental and Ford Thunderbird have dual systems. A sketch of the 1961 Thunderbird exhaust system is shown in Figure 1.

### Change in Muffler Location

Location of the muffler in the automobile exhaust system definitely affects the corrosion rates. If placed close to the engine, the muffler obviously will get hotter more quickly than if it were located at the rear of the chassis. Consequently corrosion would be less.

sequently, corrosion would be less.

Despite this, most of the 1961 automobiles have the muffler located at the extreme rear of the chassis as illustrated in Figure 1. Location of the muffler usually is determined not by engineering principles but by space limitations under the car's body. Because of the lower body silhouettes on most recent models, muffler location has been forced to the extreme rear. Many 1961 mufflers are so far to the rear that tailpipes of only a few inches are required to reach the rear bumper from the muffler.

How well these exhaust systems with mufflers in extreme rearward positions will resist corrosion remains to be seen.

### Other Design Changes

One significant exhaust system design change which may or may not affect corrosion rates is being tried on some models of the 1961 Buick. A single muffler is mounted parallel to and just behind the rear axle. The system includes a front crossover pipe to connect the exhaust manifolds on each side of the V-8 engine, an intermediate exhaust pipe from the manifold on the right side to a point just over the rear wheel, a curved exhaust pipe running over the rear axle, then the single muffler and a short tailpipe. This transverse muffler system also is used on the Oldsmobile compact car, the F-85.

muffler system also is used on the Oldsmobile compact car, the F-85.
According to Buick's showroom literature, however, dual exhaust systems still are standard equipment on some models of the Electra and are optional on all 1961 models. The dual system has not been replaced completed completed.

has not been replaced completely. Buick tried another innovation in dual exhaust design on 1960 models. Dual exhaust pipes connected each cylinder bank of the engine to a single transverse muffler behind the rear axle. Exhaust fumes from each bank entered the muffler on one end and exited through a tailpipe on the opposite end. This system had dual exhaust pipes and dual tailpipes but only a single muffler. Exhaust from the right cylinder bank entered on the right side of the muffler and exited from the left end. Exhaust from the left end. Exhaust from the left end on the muffler's left end and exited on the right end.

Although Buick made no claims in its literature for this design's longer service life or lowered corrosion rates, one can logically surmise that the design could have been an attempt to lower corrosion rates by having more uniform heating in the muffler. This would seem logical because hot exhaust fumes would be entering both ends of the muffler. No data are available on this system's performance, but since it was not used

Figure 3—Asbestos insulation is sandwiched between the inner and outer shells of some nufflers to retain heat so that the muffler will operate at higher temperatures than normal. This is one design method to control corrosion caused by acid condensate from the engine exhaust fumes.

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on 1961 models, this may be an indication of its performance.

#### Materials Used for Corrosion Control

As in most other corrosion problems, As in most other corrosion problems, design is not the only factor to be considered in corrosion control on the auto exhaust system. Materials used to fabricate and to coat mufflers also can have considerable effect in extending muffler

life by reducing corrosion.

Materials being used for corrosion ontrol on the auto muffler which will be considered in this article include zinc coated steel, aluminized steel, ceramic coated steel, chromium rich diffusion coatings and a new stainless steel specially designed for auto muffler fabrication.

#### Zinc Coated Steel

Zinc coated steel is used widely in the fabrication of auto mufflers. Sta-tistics released by some manufacturers claim that zinc coated steel can extend muffler life to 300 percent over uncoated steel.<sup>10</sup> Other manufacturers, however, believe this to be an unreasonable figure and state that zinc coated steel can extend muffler life from 50 to 75 percent over uncoated steel, but even this statement is qualified to include "in certain applications." On applications where extremely high muffler temperatures are encountered, zinc coated steel may not increase muffler life at all.<sup>2</sup>

As with other coatings used for coated steel may not increase muffler life at all.<sup>2</sup> ure and state that zinc coated steel can

As with other coatings used for corrosion control purposes, zinc coatings on mufflers must be applied with care to insure quality. The muffler also must be designed to make the most effective use of this coating to control corrosion. The use of zinc alone without quality control in material, manufacture and application may not necessarily mean added muffler life.<sup>2</sup>

One manufacturer's use of zinc coated

steel can be considered as an example. Commercially pure zinc (99.30 percent pure) is applied by hot dipping to regular carbon steel, at the rate af about one ounce of zinc per square foot. The muffler shell is coated on the inside and outside with coating thicknesses varying from 0.0008 to 0.001-inch." Zinc coated steel mufflers are marketed by AP Parts, Sears Roebuck, Montgomery Ward, Arvin Industries and others.

TECHNICAL TOPICS

Aluminized steel mufflers have been used widely in the last two years after supplies of this coated metal became adequate to satisfy the muffler manufacturers' needs. Ford used aluminized mufflers on all its cars beginning in 1960.

Aluminized steel has better heat resistance than plain steel. From a standpoint of manufacture, aluminized steel is similar to zinc with the usual forming

is similar to zinc with the usual forming and welding problems.

Some estimates have been made that aluminized steel should increase muffer life from 60 to 100 percent. On dual systems, aluminized steel could extend muffler life to two years.<sup>2</sup>

Several manufacturers are using both aluminized parts and zinc coated parts in their replacement mufflers. These two coated metals are used in specific areas or parts of the muffler requiring the

### Serious Corrosion Problems Admitted for Automobiles

"Corrosion has been a severe problem, both in the automobile body itself and in major components," according to E. W. Bernitt, vice president of American Motors Corporation.8

special resistance of each metal.1 Figure compares service life of a combination zinc-aluminized muffler with one having only some of the steel coated. Replacement mufflers with both zinc

and aluminized steel parts are manufactured by Rayco, Arvin Industries and others

About two years ago, an attempt was made to market a cast aluminum muf-

fler. Using aluminum's ability to transfer heat, the muffler was designed to warm up more quickly than steel mufwarm up more quickly than steel mur-flers and to give more controlled heat distribution achieved by variations in wall thickness which would be econom-ically possible by the use of cast alumi-num. The muffler was designed to be cast in two halves and bolted together.<sup>12</sup> But the aluminum metallurgists had

not considered the amount of heat that would have to be dissipated in the average auto muffler in heavy service. Despite the logical reasoning that aluminum's thermal conduction characteristics would eliminate some corrosion by giving more uniform heat distribu-tion, the cast aluminum muffler drasti-cally failed, some actually disintegrating after short periods of heavy service.<sup>2</sup>

### Ceramic Coated Steel

One of the latest materials to be used for corrosion control purposes in the the auto muffler is ceramic coated steel. American Motors was the first auto manufacturer to use ceramic coated mufflers as standard equipment on all its models. These exhaust systems in troduced on the 1961 Nash and Rambler cars include a tailpipe that is ceramic coated inside and outside.

The ceramic coated muffler on Nash and Rambler cars is processed as fol-lows: the muffler assembly and tailpipe are dipped in liquid slurry containing borosilicates, clay, borax, titanium dioxide and other refractory agents. After fire-hardening at 1500 F, the bluish coating is about 0.003-inch thick. Two holes in the muffler's outer surface are used to drain the surplus slurry out of the unit after dipping. These holes are later filled with stainless steel expansion plugs, the only patentable feature of the system.13

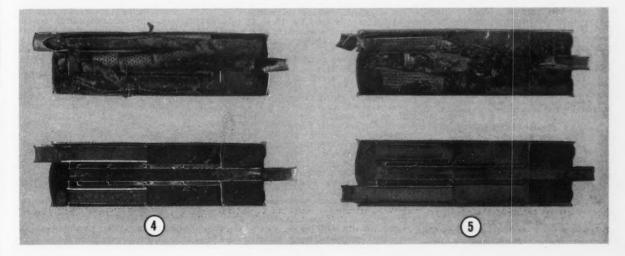
After the ceramic coating process is completed, a layer of asbestos insulation wrapped around the muffler is held in place by a zinc coated steel cover. According to Nash-Rambler show-

room literature, this ceramic coated exhaust system is guaranteed as long as the original purchaser owns the car. No

(Continued on Page 24)

Figure 4-Muffler for Cadillac autos without interchamber drain holes rigure 4—Murrier for Cadillac auros without interchamber drain holes is shown in top photograph. This top muffler had no zinc coating. Its service life was only five months for a total of 4450 miles. Another muffler for same Cadillac in bottom photograph was made of a corrosion resistant material and was designed with interchamber drain holes. The bottom muffler lasted for 24 months and a total of 21,898 miles.

Figure 5-Effectiveness of using both zinc coated and aluminized steel in mufflers is shown in the above comparison of two mufflers for Cadillacs. The top unit lasted only 8 months for 6688 miles; it had only some coated steel. Bottom muffler made of zinc coated and aluminized steel lasted 16 months for a total of 8820 miles.



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(Continued From Page 23)

mention is made in the literature, however, as to specific coverage.

Another ceramic coated muffler is available as replacement equipment from Sears Roebuck stores. Unlike the Ameri-can Motors system, Sears' guarantee spe-cifically states its coverage: "This Allstate Perma-Guard Ceramic Coated Muffler is guaranteed for five years from date of sale against failure due to rust out, blow out, wear out or failure for any reason except accident or abuse." Issued to the customer when the muffler is purchased, this guarantee also stipulates that no installation charge will be made if the ceramic coated muffler requires replace-ment for any reason excluding accident or abuse. If the failed muffler was installed by someone other than Sears, an allowance of \$2.50 is given toward installation of a new muffler.

This guarantee is unique because most

other guarantees stipulate that the equipment must remain under a single owner and that an installation charge of \$2.50 to \$3.50 will be made for re-

placements made under the guarantee. Another ceramic coated muffler with a rather specific guarantee is being distributed by Ceramicote Mufflers Limited, Toronto, Ontario, Canada, through the Everlast Muffler Mart, 1379 Dufferin St., Toronto, This muffler is sold with St., Toronto. This muffler is sold with a written guarantee "against corrosion, rust out, rot, blow out and manufacturer's defects," as long as the original purchaser of the muffler owns the car." Called Ceramicote, the ceramic coating is applied by Broome Porcelain Co., 786 Dwider History Division Control

786 Dundas Highway, Dixie, Ontario, Canada, by the following method:

1. Mufflers are purchased from various

**Backfill for Anodes** 

Ideally suited for use with anodes. Has a high carbon content and comes in sizes of  $\frac{1}{2}$ -inch x 0 to  $\frac{1}{2}$ x  $\frac{1}{2}$ s inch. In bulk or sacks. Prices on other sizes on

Special DEEP WELL Fine Coke Backfill-100 Mesh **National Carbon Anodes Magnesium Anodes** 

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manufacturers although only one is reliable for ceramic coating purposes.

Many muffler suppliers refuse to sell to Ceramicoté for obvious reasons. Muf-flers for ceramic coating normally have 20-gage steel outer shell and 24 gage inner shell with various baffle and tube

configurations inside.

2. If applied by manufacturer, paint is burned off the muffler's exterior sur-

3. Muffler is soaked one-half hour in 160 F alkaline bath.

4. Two cold water rinses.
5. Muffler is soaked one-half hour in
15 percent hydrochloric acid at room temperature.

6. Two more cold water rinses.
7. Ten-minute soak in soda-ash-borax neutralizer at 160 F.
8. Muffler is immersed and slushed in

ceramic water suspension consisting of ceramic frit milled to 2 to 3 grams residue on 200 mesh screen plus additives to control viscosity and settling rate. Bath is checked every two hours

for viscosity and contamination.

9. Muffler is drained and dried by warm air at 200 F to prevent condensation which causes the frit to run. Inlet



Figure 6-Muffler made of chromallized steel parts was struck repeatedly by hammer to show that steel is still in good condition even after 30,000 miles of continuous use for more than four years.

and outlet openings in the muffler ends are wiped clean to facilitate fit-up during installation on the automobile.

10. Muffler is fired for 10 to 11 min-

utes in reducing atmosphere by electric furnace to a dry film thickness of 2 to 4

A Ceramicote muffler was tested for short-run operation on a delivery truck found in excellent condition after 35,000 miles

Cost of each of these three ceramic coated mufflers is just a few dollars above the average replacement muffler cost. For example, Sears Roebuck is retailing its ceramic muffler for only three dollars above the cost of its most expensive heavy duty zinc coated muf-fler. The Canadian Ceramicote muffler retails for about four dollars above the usual replacement cost for zinc coated mufflers.

Because ceramic coated mufflers have been in service for less than a year, no performance data are available. One obvious problem with the ceramic coatings will be fractures during shipping and

### **Auto Muffler Condemned** For Lack of Corrosion Resistance

"It is ridiculous that a \$3500 automobile is delivered with a part (the muffler) which operates in a highly corrosive environment and is made from materials having absolutely no corrosion resistance."

Thus wrote an engineer in reply to a reader survey conreply to a reader survey conducted by an engineering magazine, seeking opinions on the materials used in American automobiles.<sup>20</sup>

storage and from rock impacts under the car. If the coating is fractured or cracked, especially if the impact is hard enough to crack the inside coating, the corrosive acids will attack the bare steel at these fractures or cracks. Also, cracks probably will retain exhaust acids which otherwise would be blown from the

Chromium Rich Diffusion Coatings

Two companies have developed processes for coating steel with chromium rich films for corrosion resistance in muffler applications. One process is called chromallizing; the other alphatiz-

Chromallizing is a relatively new Chromallizing is a relatively new technique for diffusing chromium and other metals into the surface of mild steels for heat and corrosion resistance. Developed by Chromalloy Corporation, 452 Tarrytown Road, White Plains, N.Y., this process is being evaluated by several muffler manufacturers as another possible material to prolong muffler life. Chromalloy does not make mufflers but Chromalloy does not make mufflers but offers its process for coating mild steels to fabricators of equipment requiring heat and corrosion resistance.

In production model mufflers, sheet is chromallized before forming to insure a uniform coating. Perforations or other openings are punched before chromallizing process so that the coating is not damaged during punching operations. Stainless steel rods are recommended for welding sections to-gether so that corrosion resistance of

the seams will equal that of the chrom-allized muffler body. The A chromallized auto muffler, after 30,-000 miles of continuous use for more than four years, was struck repeatedly with a hammer to show that the muffler body and internal parts were in good condition, as shown in Figure 6. This muffler was installed on a car that was operated in all kinds of road conditions in the Northeastern United States. The deep dents made by the hammer indi-cate the parts are still solid.

Cost of the chromallized mufflers, if they are put into production, will be slightly more than the average aluminized muffler but considerably less than a stainless steel muffler. Stainless are muffler but considerably less than a stainless steel muffler. Alphatizing, the second type of the stainless steel muffler. Stainless steel m

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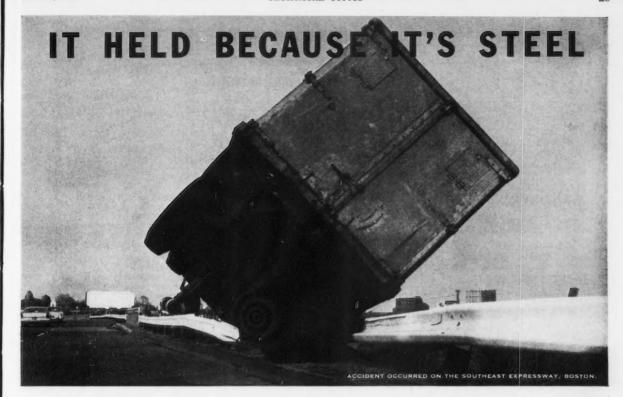
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### -Guarding Steel's Strength Is A Job For ZINC

This picture is a dramatic example of how steel guard rails are saving lives on our highways. The resilient strength of the steel rail and posts kept this truck from plunging down a steep bank to a highway below.

Results of steel guard rail installations on the New Jersey Turnpike, Cross County (Westchester, N. Y.) Parkway, Belt Parkway in New York and other major highways prove the life-saving ability of these barriers. Many of the 15,800 fatalities which in 1960 resulted from vehicles crossing to the wrong side of

the road or going off the road could have been prevented by guard rails.

Galvanized steel guard rail costs less than competitive materials such as aluminum or concrete. In addition, it is stronger than aluminum and has a shock-absorbing resiliency not present in concrete barriers. The zinc coating guards steel's strength and appearance against corrosion. The tough zinc hide can take the bangs and scratches of highway abuse without losing its protective ability.



THIS GUARD RAIL DIDN'T HAVE STEEL'S STRENGTH—Aluminum guard rail on the Long Island Expressway was broken by collision impact.

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chromium diffusion coating, is a gaseous chromium diffusion process developed by Alloy Surfaces Company, Inc., 100 South Justison St., Wilmington, Del. The term alphatizing was chosen because of the metallurgical fact that chromium in iron stabilizes the "alpha" or room temperature crystalline form of iron.

Similar to gas nitriding or carburizing, alphatizing involves the use of a process material called Alphalloy, which is placed in the treating vessel with the metal articles to be coated. The process material and work pieces need not touch. Action of the heat on the process materials produces the proper atmosphere. Reaction speed is based not on the supply of chromium but on diffusion rates, temperatures, time and the metal itself. 16

Figure 7 shows samples of alphatized AISI 1010 steel which have been ground through the case structure on one end and then immersed in 20 percent boiling nitric acid for 30 minutes. The mild steel core has been etched away by the acid, leaving the unattacked chromium

Figure 7—Coupons of AISI steel shown here received a chromium rich diffusion coating by process called alphatizing. Coupons were ground through the case structure of chromium on one end, then immersed in 20 percent boiling nitric acid for 30 minutes. Photograph shows the mild steel core has been etched away, leaving the chromium case.

### Short-Lived Mufflers Have Spawned Whole New Industry

"Of all car components, the muffler-tailpipe system is about the only one so short-lived; it has spawned a whole industry and sales chains devoted to replacing it."13

rich case which has remained tough and ductile.  $^{\text{if}}$ 

Alphatized mufflers are made from 18 and 16 gage mild steel of recommended types sheared to size or to multiples of size and alphatized in the flat. This flat stock is roll-formed into a large tube and seam welded from end to end to form the muffler body or wrapper sheet. Internal perforated tubes also are roll-formed and tack welded with a 300 series stainless steel filler rod. Muffler heads and baffles are blanked and formed from alphatized flat stock or are alphatized after forming, depending on which procedure is more economical and convenient."

Figure 8 shows a section of perforated tube inside a test muffler in service on a beverage delivery truck for 500,000 miles. This section has been lightly etched at one end to show that the case structure is still intact. Figure 9 is a photograph of the muffler before it was dismantled for inspection.

Truck mufflers generally fail from heat rather than from corrosion because truck service ordinarily involves long runs, thus preventing the accumulation of acid condensation in the muffler.

Because of the 40 percent chromium content of alphatized steel, this material probably can adequately resist the extremely corrosive mixed acids that are formed during automobile short run operation. Field tests by two auto muffler manufacturers have shown this material to have outstanding characteristics for use as car muffler components. However, passenger car mufflers require use of large tonnages of thin gage steel

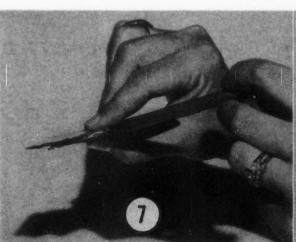
(26 through 19 gage) in coil form. In the past, economic alphatizing of steel in coil form was not possible, but a development program is being conducted to eliminate this bottleneck so that alphatized auto mufflers can be marketed.<sup>17</sup>

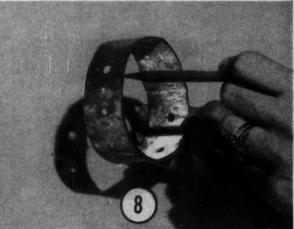
Stainless Steel

The latest development in muffler manufacture has been the introduction of a stainless steel muffler on the 1961 Ford Thunderbird. This designation is not exact; only 50 percent of the parts in this muffler are stainless steel. Cost of the high strength stainless series has prohibited use of these materials previously, but Allegheny Ludlum Steel Corporation, Pittsburgh, Pa., has developed a modified Type 410 stainless called MF-1 for muffler fabrication. It has 11 percent chrome, 0.36 percent titanium and other elements added to give corrosion resistant characteristics plus good ductility and ease of welding.

of welding. On the 1961 Thunderbird, MF-1 stainless is used for the inner shell, one baffle and the heads on the dual mufflers. Figure 10 shows the stainless parts being inserted in the aluminized shell. The inner shell and baffle are 0.036-gage stainless; the heads are 0.048-gage. Other parts of the muffler are aluminized steel, including the outer shell. Ford claims that the corrosion resistant stainless is not needed in the two resonators included in the Thunderbird ex-

Figure 8—Section of the perforated tube inside a test muffler installed on a delivery truck for 500,000 miles. The section shown here has been lightly etched to show that the chromium rich case structure is still intact after the truck service exposure.





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Figure 9—Truck muffler made of steel with a chromium diffusion coating was still in good condition after 500,000 miles. Figure 8 shows a section of the internal tubing from inside this muffler.

### Where Auto Muffler Corrosion Begins . . .

Engineers say that each gallon of gasoline burned creates more than a gallon of acid impregnated water in vapor form that passes through the automobile exhaust system. Devastating corrosion begins when this highly acidic moisture condenses in the muffler.3

haust system.4 A cut-away sketch of the Thunderbird stainless muffler is shown in Figure 11. This muffler is manufactured by Arvin Industries, Inc., Columbus, Ind.

Arvin also is marketing 16 different replacement mufflers made of the new MF-1 stainless steel. These mufflers are designed to fit more than 90 percent of the American cars from 1955 to 1961 and several cars dating back to 1949.18

Cost of the stainless mufflers will be about twice that of a conventional replacement muffler.18

The MF-1 steel also was developed for use in anti-smog devices. A special article on these smog burners for automotive use appears on Page 47 of this issue's Record and Report Section.

Accelerated corrosion tests conducted by Arvin Industries on the stainless muffler show it has no signs of de-

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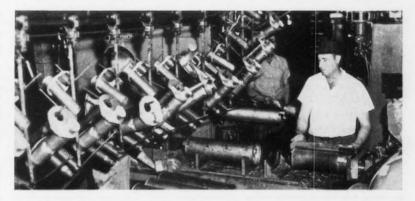


Figure 10—Modified Type 410 stainless steel (called MF-1) is being used for replacement mufflers. Here the stainless parts are being assembled at Arvin Industries, Inc., Columbus, Ind. The inner shell, one baffle and the heads are made of the stainless for the dual mufflers on the 1961 Ford Thunderbird.

### Sources of Information

In its research for this staff feature, CORROSION magazine solicited information and data from 17 of the major manufacturers of automotive exhaust systems in this country and from companies directly involved with

exhaust systems.

The CORROSION staff.
thanks the following seven companies for the data and information submitted for this article: Alloy Surfaces Com-pany, William Jenkins Advertising, Inc., Philodelphia, Pa.,

Arvin Industries, Inc., Columbus, Arvin Industries, Inc., Columbus, Ind., Broome Porcelain Co., Dixie, Ontarlo, Canada, through the cooperation of Corrosion Service Limited, Taronto, Canada, Bettinger Corporation, Milford, Mass., and its agency Ruder & Finn Inc., New York, N.Y. AP Parts Corporation, Toledo, Ohio, Chromalloy Corporation, West Nyack, N.Y., and its agency Greif-Associates, Inc., New York, N.Y., and Rayco Manufacturing Co., Paramus,

The following two firms preferred not to publish any data or information concerning their exhaust, system products. Walker Manufacturing Company, Racine, Wis, and Soiar Aircraft Company, San Diego, Cal., working on his cost protective coatings.

No replies to inquiries were received from the fallowing: Midas, Inc., International Parts Corp., Mar Pro, Inc., Grand Automotive Products, Powell Muffler Company, Inc., and Reynolds Metals Company.

Ce



(Continued From Page 27)

terioration after more than five times the number of hours usually sufficient to corrode ordinary steel. Subjected to liquid condensates from engine exhausts, the MF-1 steel lasted 2100 hours, aluminized steel 900 hours and carbon steel less than 400 hours.

Arvin Industries' enthusiasm for the new stainless muffler is indicated by their five-year, unconditional guarantee (except for accidents and abuse) to the owner on whose car the stainless muffler is installed. 19

Tailpipe Corrosion Problems

Excluding the ceramic coated tail-pipes on the Nash and Rambler cars, little has been done to solve the cor-rosion problems on tailpipes. This may be the area in which the manufacturers

make their next move to eliminate at least a part of the problem that cost car owners an estimated \$175 million in

1960 for tailpipe replacements alone.

Apparently, no effort is made by the manufacturers to relieve stresses that are set up in bending the tailpipes which could cause excessive corrosion. Operating temperatures of the tailpipe and driving habits of the car owner are considered more significant in determin-ing tailpipe service life than stresses set up in pipe bends. Some thinning of the material may occur at the bends and a small degree of stress, but these factors are not considered significant enough to add to tailpipe life if stress relief were accomplished in manufacture. Sufficient heating probably takes place during operation of the car after the tailpipe is installed to relieve most of the stress created in the bends.<sup>10</sup>

Two muffler and tailpipe manufacturers, however, are concerned about a corrosion problem that does not involve the service life of the equipment. These two companies apply a temporary rust preventive coating to tailpipes and exhaust pipes so dealers will not be installing tailpipes already covered with rust. The coatings are applied to pre-vent corrosion on the tailpipes during

vent corrosion on the tailpipes during shipping and storage only.

These two companies are Walker Manufacturing Company, which applies what is described in the catalog as Corrosite 810, and AP Parts Corporation, AP Bldg., Toledo 1, Ohio, Walker did not voluntee; any information about did not volunteer any information about its coating or about any of its equipment when asked for additional information.

AP Parts applies a phosphate oil solution to its tailpipes and exhaust pipes after fabrication to prevent rust during storage. Figure 12 shows two sections storage. Figure 12 shows two sections of tailpipes, one coated with AP's rust preventive compound and the other uncoated. Both were subjected to a salt spray test for 19 hours, considered equivalent to months of storage under the most unfavorable conditions.

AP Parts has installed a 3000 square-foot Corrosion Control Center at its plant for application of this rust pre-ventive compound to tailpipes. Figure 13 shows two views of this conveyor line for application and drying of the pipes, accomplished in one continuous operation.

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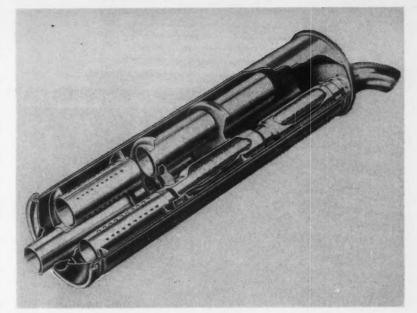
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TECHNICAL TOPICS

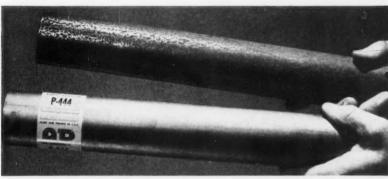
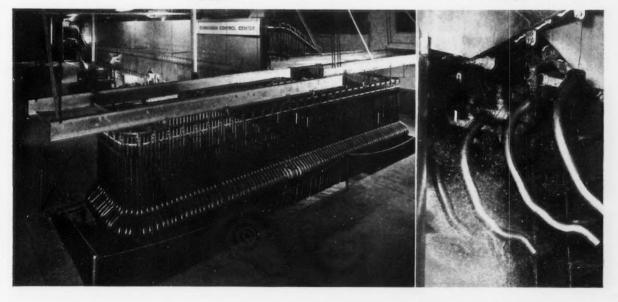


Figure 11-Cut-away sketch of the Thunderbird stainless steel muffler. Only 50 percent of the parts are made of the modified Type 410 stainless developed by Allegheny Ludlum Steel Corporation.

Figure 12—Bottom tailpipe has been coated with a phosphate oil solution to prevent rust during shipping and storage. Upper pipe was not coated. Both pipes were exposed to a salt spray test for 19 hours, considered equivalent to months of storage under the most unfavorable conditions. Primary purpose of this corrosion control coating is to eliminate rust colored pipes in dealer's inventories so that he is not forced to replace the customer's rusty tailpipe with another rusty pipe.

Figure 13-Views of the 3000 square-foot Corrosion Control Center of AP Parts Corporation, Toledo, Ohio, where phosphate oil solutions are applied and dried on tailpipes and exhaust pipes after fabrication to eliminate rust and corrosion on the pipes during shipping and storage.



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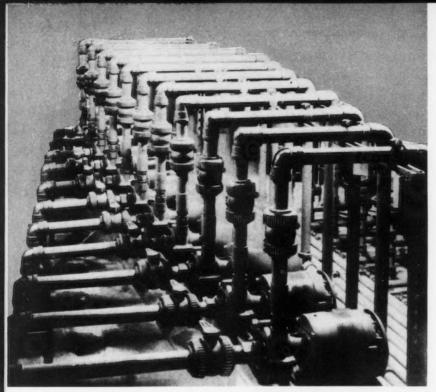


Figure 1—Plastic pipe, valves, fittings and pumps handling photographic developer solutions at Patrick Air Force Base in Florida. Pumps are molded from ABS polymer. Balance of system is rigid PVC.

#### Abstract

Abstract

Abstract

Describes principal characteristics of thermoplastics currently used for corrosion resistance. Some of the advantages of plastic piping over metallic piping are discussed. Types of plastic materials described briefly include polyethylene, ABS, cellulose acetate butyrate, vinylidene chloride, PVC and chlorinated polyether. Also describes plastic lined steel pipe, joints, fittings and valves. Additional data given on PVC. case histories given on service of PVC with illustrations of several installations.

6.6.8

Russell W. Johnson and Allyn E. Webb

Kraloy/Chemtrol Company Santa Ana, California

### Introduction

PLASTIC PIPE should no longer be Considered solely an interesting material with a promising future. Because plastic piping has been used in industrial corrosive services for over 20 years in Europe and in this country for almost 10 years, the background of experience now is sufficient for sound decisions to be made on applications of plastic piping for corrosion control.

Chief reasons for the increased use of plastic pipe are advantages plastic has over other types of materials in some environments such as the five advantages listed below:

1. Reliable, reasonable long term test information now is available on the reaction between plastic pipe and most chemicals and also external environ-ments. Extrapolation often can be used for information on situations which differ from those previously experienced. All components of a fluid must be considered for their possible effect on plastic rather than considering only the major components. For example, brighteners or wetting agents in some electroplating baths contain organics which are more agressive than chromic or sulfuric acid.

2. Good resistance to fumes or spillings and to most underground and atmospheric environments are achieved when plastics are used. The outside of plastic pipe does not require protection against external corrosion as does steel

3. Low friction loss factor and surfaces which tend to discourage deposits other advantages. Extruded with surface characteristics similar to PVC is especially good in this quality. For design purposes, steel pipe usually is given a C factor of 100; copper or brass, 130; and plastic, 150. This means that plastic pipe offers greater capacities in equal sizes or equal capacities in smaller sizes than other pipe.

4. Experience in the field shows that plastic pipe with socket fittings can be installed faster and at less cost than most other suitable chemical piping materials. Usually the number of men required is reduced for installation because of plastic's lighter weight. This is espe-cially significant in overhead and other relatively inaccessible areas. Hangers can be of lighter construction when plastic piping is used although this advantage sometimes is lost because of the necessity for more frequent supports, especially when high operating temperatures

must be considered.
5. Plastic pipe eliminates the problem of galvanic corrosion between dissimilar metals. This is a serious problem which often is overlooked in metallic piping systems. Plastic pipe also has good insulating qualities which minimize condensation on exterior surfaces and reduce heat losses.

However, despite these advantages, thermopalstic pipe should not be con-sidered for services in which plastic pipe not suitable such as temperature above 250 F, pressures above 150 to 230 psi and areas subjected to excessive physical abuse.

Types of Pipe Are Compared

In this article, various types of plastic pipe now in use are compared as to merits and limitations, a few typical case histories are given and some mat-ters helpful to the corrosion engineer in getting satisfactory performance from properly selected, properly installed plastic piping systems are explained.

The more important thermoplastic piping materials for industrial uses are described below.

Polyethylene

The advantages of polyethylene include flexibility (can be coiled), good corrosion resistance and lowest cost of the plastics. Several hundred feet can be uncoiled and installed with one set of fittings.

But polyethylene also has the following disadvantages: (1) low operating pressures from 50 to 75 pounds, (2) poor hydrocarbon solvent resistance, (3) low temperature resistance, about 120 F, (4) subject to cracking under some stress conditions and (5) high permeability to gasses.

Some new high density polyethylenes have higher molecular weights, greater rigidity and tensile strength properties than the earlier polyethylenes and therefore can be used to handle higher temperatures and pressures. Typical uses of polyethylene pipe include low pressure gravity flow salt water lines, ore leaching operations and oil well collecting lines. Styrene or nylon fittings are not

as resistant to corrosives generally as are polypropylene.

ABS (Acrylonitrile-Butadiene-Styrene)

ABS is a rigid plastic material available in 10-foot lengths, has good impact strength and tensile properties, Maximum operating temperature is 180 F. ABS pipe has good resistance to most dilute and some concentrated acids, alkalies and salt solutions but has poor resistance to solvents. Its earliest and most successful application was in water treating and sewage systems and irriga-tion systems. Recently, the use of ABS materials has been expanded in the

# Thermoplastic Pipe, **Fittings** and **Equipment** for

**Corrosion Control**\*



Figure 2—Two solid chlorinated polyether ball valves in service at 200 F in hydrochloric acid and wet chlorine. A plastic flange connects to a glass line.

chemical processing and mining fields. Most of this pipe is joined by solvent welding to socket fittings which are readily available in sizes through four

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Cellulose Acetate Butyrate

This butyrate accounts for about 20 percent of the total plastic pipe market but cent of the total plastic pipe market but recently has lost favor because of availability of materials with better properties. Cellulose has moderately good chemical resistance but tends to embrittle with age. It has been used in considerable volume for gas service lines. Its flexibility permitted snaking of the plastic line through corroded metal pipe. It also is used widely for salt water and crude oil where its resalt water and crude oil where its resistance to paraffin build-up is important. Butyrate pipe made possible dimensioned SWP fitting (Solvent Weld Pipe for solvent cementing). This thin walled fitting is used extensively in irrigation and natural gas lines where low pressures are encountered.

Vinylidene Chloride

Once very popular, vinylidene chloride is giving away to other plastic materials. It has fairly good corrosion resistance but is more expensive than newer materials such as PVC and is handicapped by low impact strength and relatively poor resistance to creep under loads. It is used successfully as a metal pipe lining.

PVC (Polyvinyl Chloride)

PVC, the most versatile of the thermoplastic piping materials, enjoys

\*Revision of a paper titled "Plastic Pipe Systems for Corrosion Resistance" presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, N.Y., March 13-17, 1961.

the fastest growth, especially for industrial applications. PVC is relatively inexpensive, has good physical strength and dimensional stability, excellent chemical resistance except for solvents and has the advantage of being flame resistant. It is produced in two types. Type 1 is designed for normal impact, being superior in all respects except impact strength; Type 2 is high impact material. PVC pipe is produced in sizes from one-half inch through 12 inches, usually in 20 foot lengths and can be joined to threaded, solvent welded, flanged or other fittings. A variety of wall thicknesses is offered with outside diameters in iron pipe sizes, permitting the use of standard threading tools, flangers with standard bolt circles, or mating with fittings of other material. Complete lines of PVC fittings and valves are available so that entire process piping systems can be designed of this material. (See Figure 1.)

A new type of vinyl piping material, polyvinyldichloride, is described as capable of withstanding temperatures 60 F higher than other vinyls, but it is not available in commercial quantities.

Chlorinated Polyether

Chlorinated polyether has been in in-dustrial use for valves for a considersiderable time with outstanding success. It has the broadest corrosion resistance of the structural thermoplastic materials and can be operated continuously at temperatures to 250 F. Components are available in the form of extruded pipe, lined metal pipe, molded fittings, valves, pumps and lined metal fittings, valves and pumps. Most installations to date have been for severe corrosive exposures due to relatively high price, but its price has not prevented this polyether from a rapid development and acceptance. Its greater corrosion and temperature resistance generally justifies its higher cost in many instances. (See Figure 2.)

Plastic Lined Steel Pipe

Plasticized polyvinyl chloride (or plastisol) is used to form a relatively thick, seamless pipe lining for flanged or grooved pipe spools and fittings. Chlorinated polyether lined pipe is available for service at higher temperature. Thin thermosetting plastic coatings have per-formed well for many years. These latter include phenolics and epoxies.

Jointing and Fittings

Methods of joining plastic pipe are much the same as those used for metal pipe and include the following:

Screwed IPS connections—Threading

tends to weaken the pipe because of the

notch effect and should not be used in pipe lighter than Schedule 80. Flanged IPS connections—these are made up from threaded pipe and flanges, plain end pipe with solvent weld flanges. In sizes larger than six inches, flanges are made up of plate material, gas welded to the plain end pipe.

Victaullic grooved—Quick coupling

Solvent or solvent cemented-These give the strongest joint but cannot be torn down and re-assembled easily.

There are two classes of thermoplastic There are two classes of thermoplastic pipe fittings exclusive of the insert type: Schedule 40 fittings are divided into light weight, medium weight or utility grades, and Schedule 80 is the heavy duty industrial fitting. These are either light walled or heavy walled and are (Continued on Pages 32)

(Continued on Page 32)

### Thermoplastic Equipment

(Continued From Page 31)

specified according to the pressure of the system to be piped. Prices vary with wall thickness.

### Many Types of Valves Available

Many types of valves are available. Most widely used are plastic ball (See Figure 3) and plastic bodied Saunders patent diaphragm types. Ball valves feature full flow, no pressure drop and quarter turn shut-off; the diaphragm valves are selected for throttling service primarily.

Diaphragm valves also are available lined with chlorinated polyether in cast iron sizes through 8 inches. Also available are globe, needle, ball-check, foot, three-way and cock valves produced by injection molding from any of the popular corrosion resistant plastics. Metal valves and fittings coated with fluorocarbon also are available to handle high temperature corrosives.

#### Structural and Mechanical Considerations

Several important structural and mechanical considerations must be kept in mind when designing plastic piping systems. These include long term pressure and temperature performance, proper support of the system with consideration given to pipe size, wall thickness and internal and external temperatures, provision for expansion and contractions and consideration of water hammer and shock loads.

Reliable information on these design considerations is available from manufacturers.



Figure 3—Solid PVC ball valves in service with stainless steel. Use of plastic avoids galvanic corrosion problem often found if a dissimilar metal were used.

### Some Case Histories of Applications

Type 1 and Type 2 PVC

Used for circulating electrolyte in copper refineries, these PVC systems usually operate at 140 to 150 F and at 25 to 30 psi. Some installations have operated for over four years with excellent results and a minimum of maintenance. Some unanticipated benefits were derived from the use of plastic pipe in this service. In this large installation involving several hundred cells, significant improvement has been effected in reducing heat loss and contamination of the electrolyte by corrosion products. Cells in which plastic liners were used showed further improvement for the same reasons.

PVC and Plastic Lined Metal Pipe

In electroplating plants, PVC and plastic lined metal pipe has proved successful for continuous re-circulation in large installations. This involves piping of delicately balanced plating solutions from tanks through filters and heat exchangers and back to plating tanks.

An eastern food processing company is using PVC pipe and fittings to handle dilute acetic acid. PVC was selected because of its resistance to the acid and to the cinder bed in which the pipe was burried, also for its value in maintaining the original flavor of the product. This pipe line, re-located after four years, was found in excellent condition, internally and externally. This points up the fact that, when a plastic is found to be resistant to an environment, it is likely to remain unaffected for a long time. This is not always true with materials that deteriorate progressively as time passes.

De-Ionized Water Service

A television tube manufacturer uses PVC pipe, fittings and valves to handle de-ionized, distilled and demineralized water. In this manufacturing process, no contamination of the water can be tolerated which might affect the finished products.

Gas Utility Lines

A natural gas utility in the west has installed over three million feet of PVC pipe in sizes from one-half inch through two inches. Installation of gas distribution service and gas mains began in 1953 and in 1958. Results have been satisfactory. The utility company plans to continue its use of plastic pipe at the rate of 400,000 feet of two-inch and 200,000 feet of one-half and three-fourth inch pipe yearly. Careful records kept by this company show plastic pipe gives substantial savings over other materials, both in material cost and installation labor.

### Suggested Purchasing Practices

Plastic pipe of the same material may vary significantly in quality from one manufacturer to another. Consequently, minimum compliance with a specification will not always insure receiving the best quality material. One of the best ways to be sure material is of the desired quality is to buy from responsible suppliers only. In specifying plastic pipe and fittings, it is advisable to consult the supplier who often can give advice that will save money and time, thus giving better assurance of satisfactory service for the installation.

The purchaser should also be present and supervise installation to be certain that all specifications are met and that the work is done with proper techniques by trained men

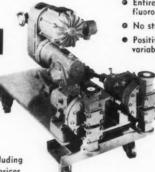
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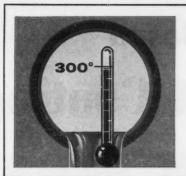
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### PROTECTION . . . THAT REALLY WORKS!

If you've ever had a pipe deteriorate, you know how serious it can be. Fibercast stands up where others simply won't do. Produced under a carefully controlled manufacturing process, its solid centrifugally cast walls provide positive protection against high temperatures in corrosive environments.

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Rugged pipe carries 94% of known corrosive solutions. Available now in sizes from 2" to 8"

Heat and corrosion failures cost money. That's why it's important to consider the maximum protection you get with Fibercast epoxy pipe. Protection against premature fouling, generally attributed to operating temperatures and corrosive solutions. Protection against intermittent replacements, downtime—added costs for new materials and labor.

Years of actual operation in field use, prove Fibercast outlasts other kinds of pipe. Even more expensive metal pipe, or pipe with thermoplastic interior coatings cannot match Fibercast's resin rich interior.

### Comparative Life Data

Report after report shows that Fibercast does outperform other types of pipe in terms of long service life. Basing Fibercast Grade J at 100% as unit life, comparable ratings show: Aluminum, 26%. Brass (RED), 74%. Rubber Hose, 21%. Stainless Steel (304-40), 31.1% Asbestos (cement C-100), 23.7%.

### Handles 94% of Known Corrosive Chemical Solutions

Out of 338 common corrosive solutions, Fibercast safely handles 320. Not only does it provide superior resistance to corrosion, heat and pressure—it also has the outstanding ability to maintain the purity of the solutions it carries. The pipe has a glass-smooth interior with a Hazen-Williams C-Flow Factor of 147. This cuts friction losses. Encourages flow at intended pressures. Resists deposit

build-up. Dielectric properties ward off electrolytic action.

Fibercast owes its long life—and its special resistance to heat, pressure, corrosion, contamination, electrolytic action—to the exclusive way it is built. Fibercast is a centrifugally cast thermoset epoxy resin reinforced pipe with multiple layers of seamless braided glass fiber sleeving or especially woven glass fabric. Its body of woven glass fibers, impregnated with epoxy

one-fourth the weight of steel). Yet it even has structural stability and strength for installation on span racks with the normal metal pipe spacing.

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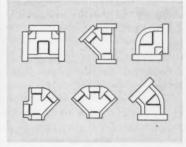


FIELD USE PROVES RESISTANCE TO COR-ROSION . . . 1 Plastic-coated steel nipple (right), used in salt water supply well, corroded and lost strength after 3 months. Fibercast (left), used in same installation for 3 years still shows no loss of strength.

resin chemically cured at elevated temperatures provides remarkable ability to withstand high pressure and temperature in corrosive environments.

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# Polyester and Epoxy Based Non-Solvent Coatings

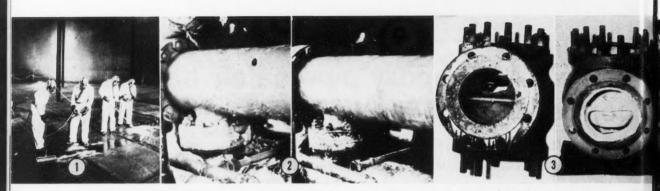


Figure 1—Glass reinforced isopolyester coating being applied to bottom and up tank side two to three feet of a 140-foot diameter by 20-foot high mild steel tank to resist corrosion of sour crude petroleum. Figure 2—Repair of an 8-inch diameter pipe badly pitted from hot salt water service in a petrochemical plant (in left photograph). Same pipe in

repair condition is at right. Figure 3—Petrochemical plant valve at left corroded to failure in hot salt water service. Valve replacement was required in about six months. The valve as repaired at right is continuing to give satisfactory service after two years' service.

### Introduction

REACTIVE RESINS for compounds containing no solvents are being used as coatings to form films having positive sealing characteristics, minimum change with age and temperature differences and resistance to most chemical agents and elements normally deleterious to conventional coatings.

The principle involved for these non-solvent coatings is the use of so-called reactive resins as bases to compounds containing no solvents or other liquid constituents which do not chemically react in polymerization to a solid state.

Conventional thin films for corrosion control generally are applied with carrier solvents which evaporate in the drying or cure of the film. These films are porous, allowing moisture and air to permeate the film. These coatings, therefore, use corrosion inhibiting pigments as components which are essential for effective corrosion control.

In non-solvent reacted resin coatings, inhibiting pigments have no opportunity to act because the pigments are locked in by the chemically inert coating. Pigments and other fillers act mainly as reinforcement. They increase toughness and impact resistance and improve properties such as low moisture absorption, high heat distortion and adhesive and cohesive characteristics. They also contribute to the tensile, compressive, shear and flexural strengths where supporting structural requirements are demanded in a coating.

Two newly developed plastic coating materials which conform to this reactive principle are dis-

cussed in this article. They are based on a polyester resin and an epoxy resin.

Both these non-solvent coatings exhibit characteristics considered ideal for organic films used to control corrosion, as follows:

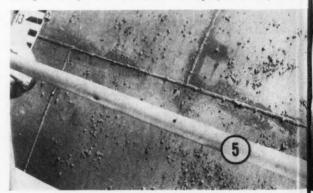
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- 1. As close to zero shrinkage during gel and film cure as possible.
- 2. Coefficients of thermal expansion sufficiently matching steel or other substrates to avoid stresses which would exceed elastic limits and bond strengths of the relatively thick film throughout the operating temperature range.
- 3. The most completely reacted, hence the most chemically inert and stable state of the coating com-

Figure 5—Six-coat vinyl system applied in 1951 to a large irrigation control gate is shown as it appeared in 1959 with rust nodules over deep pitting which indicated pinholing and probable penetration of coating at these points for most or all of the eight-year service period.



# for Corrosion Control\*

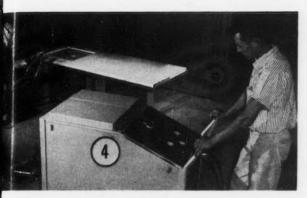


Figure 4—Self-contained console unit designed by Hodges Chemicals Company for zero-pot-life reactive resin coating application which preheats and delivers positively proportioned, reactive resin and curing agent at controlled differential temperatures to a non-fouling combining valve and mixing chamber before atomization by conventional paint spray gun.

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4. A mechanically stable compound leading to an unchanging permanent film with dimensional stability, no cold flow, high resistance to abrasion, erosion and high mechanical strength.

5. A homogeneously sound and non-porous compound, without voids or unreacted monomer, with

(Continued on Page 36)

\*Revision of a paper titled "Non-Solvent Coatings for Corrosion Control" presented at the Western Region Conference, National Association of Corrosion Engineers, October 6-7, 1960, San Francisco, Cal.

Figure 6—One coat, non-solvent reacted epoxy based coating applied with special process equipment to an irrigation gate. Service exposure was partial immersion in fresh water about 40 percent of the time. After 28 months, the coating shows good durability with no change and no evidence of penetration due to pinholing. Figure 7—Mild steel, truck tank lined with non-solvent coating is used to transport 50 percent

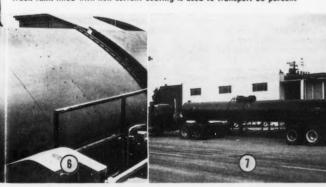
William C. Hodges Hodges Chemical Company Mountain View, California

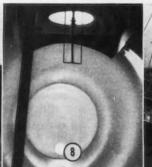
John J. Bogner Chemical Process Company Redwood City, California

### Abstract

Discusses non-solvent coatings based on polyester and epoxy resins that give thicker film thicknesses in one application than do conventional solvent type coatings. Briefly describes special spraying equipment required for these non-solvent systems. Suggested application procedure is given. Comparison data are given on shrinkage rates of nonsolvent and solvent type epoxies. Cost comparisons are made also between the two systems, showing the cost advantages derived from the thick, onecoat applications obtainable with the non-solvent coatings. Photographic examples are given of applications using the non-solvent coatings. Tabular data are included on chemical resistance of nonsolvent and solvent types of epoxy coatings after a six-month continuous immersion test on sandblasted steel coupons. 5.4.5

caustic soda solution in which iron pick-up or other contamination cannot be tolerated. Figure 8—Interior of a mild steel, truck tank lined with non-solvent epoxy based coating. Tank is used to transport spent acid, a petroleum woste product with high acid effect, used as a fuel. Figure 9—Application of non-solvent, reactive epoxy based coating to starboard waterline area of a US Navy attack transport in mothball fleet.



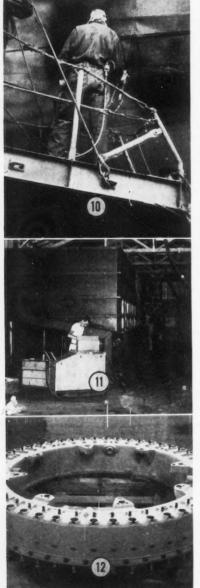




### Polvester

and

**Epoxy Based** Non-Solvent Coatings



(Continued From Page 35)

low gas and moisture transmission, permeation and absorption rates.

6. Relatively low cost of application, thus economically useful for the wide variety of materials normally requiring protection against corrosion.

Polyester Based Compounds

The first coating to be discussed is based on a polyester resin and can be applied to thicknesses of 125 to 250 mils. The use of isophthalic polyesters (referred to as isopolyesters) is dis-cussed rather than the conventional or orthophthalic polyester resins.

The choice of isophthalic rather than conventional phthalic polyesters resulted from evaluations of the isophthalic series: beter chemical resistance and better adhesion to dense materials includ-

ing metal and glass.

Experience has shown that polyester resins in the manufacture of glass reinforced equipment give good corrosion resistance (such as portable tanks, hoods, fume ducts and pipes). Thus, it was natural to investigate the use of glass reinforced polyesters as a coating material.

Two years ago isopolyester gum resins, as well as suitable equipment to apply glass reinforced polyester coatings, became commercially available. These two facts triggered the program described in this article.

Isophthalic acid, a resin raw material derived from the petroleum industry, was first made commercially in 1956. The incorporation of isophthalic acid in a polyester resin formulation produces polyester resin formulation produces polyesters with significantly improved physical properties over conventional polyesters. Adhesion, chemical resist-ance, ease of wetting and durability are some of the improved physical characteristics.

These improvements were demonstrated first when isopolyesters were used instead of conventional polyesters in the manufacture of fiberglass reinforced laminates. Later, isopolyesters with their excellent adhesion characteristics. istics proved to be a natural binder for plastic patching compounds. Because these improvements were available at no extra cost, isopolyester was used as a binder for the chopped glass fiber in the evaluation of glass reinforced coat-

Until two years ago, application of a polyester coating over a large area was a problem. Polyesters are a solventless catalyzed system with a short working life at room temperature. Several guns now are available which enable the applicator to vary the working life of the polyester from a few hours to sev-eral days. These spray systems are equipped with glass choppers. Thus, application of glass reinforced

Navy attack transport where previous protection by conventional solvent-carrying marine paints was inadequate. Figure 11—Wine fermenting tanks being lined with reactive epoxy resin coating system. Wine company specified 15 to 20 mils, which is almost double the maximum protection against wear in the fermenter tanks. This thick coating was sprayed in a single coating operation. Figure 12—Bronze beer can filler which is caustic cleaned daily. A multicoat solvent epoxy system failed within weeks and permitted bronze particles to contaminate the beer. Reacted epoxy lining on

Figure 10-Pitting of plates along waterline of

the can filler has had no failures after about 21/2 years' continuous service.

isopolyester coatings have been simplified. Application systems keep the catalyzed resin, or the catalyst, separate from the promoted resin until the coating material is spread.

This glass and isopolyester mix applied as a thick coating has excellent resistance to acid solutions, salt solutions and many solvents. Continuous exposure at temperatures to 180 F does not appreciably affect this coating. With not appreciately affect this coating. With proper preparation, isophthalic glass re-inforced coatings can be applied suc-cessfully over a variety of surfaces such as metal, wood and concrete.

as metal, wood and concrete.

Polyester systems are the reactive solvent type. The styrene monomer, used to reduce the viscosity of the base resin, takes part in the reaction, co-polyment with the base resin. merizing with the base resin, thereby becoming part of the coating itself. Elimination of evaporation losses presents obvious economies and reduction in health and fire hazards. Toxicology

is not a serious problem.
Solidification mechanism of the polyester type material provides fast con-

### **Coating Clinic**

See Page 78 of this issue for questions and answers in the industrial coatings field. Questions include such subiects as sandblasting on storage tank roofs, rotary versus piston type air compressors, coating coverage and coatings for tanks exposed to sulfur dioxide fumes.

version from liquid to solid. This allows the deposit of thick films with a minimum of sagging and drainage.

Experience has proved that an iso-polyester of high reactivity and low acid number is the optimum formulation for the several resin compounds used in the coating and lining systems.

Suggested Application Procedure

For a successful application of glass reinforced isopolyester coating, the following five-step procedure should be carefully observed:

1. Thorough surface preparation by sandblasting metal where possible (if not, wire brushing) to remove scale, dirt, rust and oil traces. Concrete should be acid etched; wood should be rough sanded.

2. Application of a thin coat of isopolyester primer (3 to 6 mils).
3. Holes and cracks in the substrate are filled with an isopolyester patching compound. Rivets, weld lines, sharp corners and sharp angles are covered with the same isopolyester patching com-

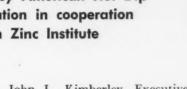
4. Application of glass reinforced coat f isopolyester. Thickness should be

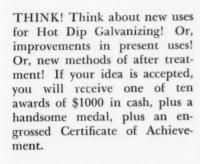
(Continued on Page 38)

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This is not a contest—it is a search for new ideas. Your entry will not be judged against others, but solely on its merit and value in developing new applications and markets for Hot Dip Galvanizing. If your idea, in the opinion of the judges, is of practical value to the industry, you will be cited for an award—promptly.

The Hot Dip Galvanizing Industry is anxious to receive ideas of this type; therefore, the judges reserve the right to present more than 10 awards, if the entries warrant.

# These well-known men will act as judges

Dr. Clarence H. Lorig, Technical Director, Battelle Memorial Institute and Past President American Society for Metals. Mr. John R. Daesen, Technical Director, American Hot Dip Galvanizers Association. Mr.

John L. Kimberley, Executive Vice President, American Zinc Institute.

### Anyone is eligible to enter

Anyone in the world (except members of the American Hot Dip Galvanizers Association and the American Zinc Institute, and their employees and advertising agencies) may submit one or more entries.

Business firms or corporations may submit entries under their business name, instead of as individuals, if they choose.

Entries will be considered by the judges promptly upon their receipt. No entry received after April 30, 1962 will be considered.

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### Each entry must contain:

- (a) Description and documentation of application.
- (b) Case history of the applica-



Galvanizers International Award

tion or process accompanied by photo, drawings, formulae, etc.

- (c) All technical data needed for the utilization of the idea submitted.
- (d) Release of the application or idea for general use without payment or royalty other than the \$1000 award.

### Other conditions:

The decision of the judges will be final.

Award-winning ideas will be retained by the American Hot Dip Galvanizers Association for dissemination throughout industry. Other entries will be returned.

No formal entry blank is required. The entry should be accompanied by your name, address and business connection.

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Note: For information on galvanizing, write to the above address for name and location of the American Hot Dip Galvanizers Association member nearest you.

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### **Polyester Based Coating Physical Characteristics**

Tensile strength	12,000 to 15,000 psi
Compressive strength	17,000 to 20,000 psi
Shear strength	12,000 to 14,000 psi
Flexural strength	25,000 to 30,000 psi

(Continued From Page 36)

from 125 to 250 mils. Glass content should be 25 to 30 percent with a chopped fiber length of one to two inches. Applied with a spray system equipped with an air driven glass chopper, the coating is rolled and compacted with a screen roller to get a reinforced coat as freee of air as possibe, as shown in Figure 1.

5. Finish coat of isopolyester surfacing resin is applied 3 to 6 mils thick.

Physical characteristics of this polyester based coating given on the insert

printed on this page

Comprehensive chemical resistance data are available for glass reinforced isopolyester laminates. Tests for glass reinforced isopolyester coatings are being conducted. Corrosion resistance to specific chemicals should be checked before a large scale coating operation is undertaken.

Raw material costs for a 125-mil iso-polyester coating is about 40 cents per square foot, Labor costs will vary from 60 cents to \$1.60 per square foot, depending on such factors as staging and accessibility.

Use of pigmented isopolyesters for exterior maintenance coatings is being investigated. Corrosion resistance requirements of such coatings are not as

Other applications of these glass reinforced coatings for field maintenance include temporary repairs of leaks and cracks in pipes caused by corrosion. These repairs usually are made with isopolyester patching compound and isopolyesters reinforced with glass tape, mat and cloth. Such repairs give considerable savings in down time and labor. Two reasir examples are chewn. labor. Two repair examples are shown

in Figures 2 and 3.

The use of glass reinforced isopoly ester corrosion resistant coatings is still experimental, but over 250 large scale applications have been made in three western states during the past two years. Few of these have failed; failures have been caused by improper application techniques, heavy toats of clear unreinforced isopolyeste's or service in unapproved environments.

As more data are gathered and new evaluations made, the use of glass reinforced isopolyester coatings will become more generally adopted in the maintenance field and in the fabrication of equipment and parts for corrosion re-sistance applications.

Special Spray Equipment Used

Until special methods for spray application of these new compounds re-cently were developed, much of the potential achievements was supposition and conjecture. But now, many successful commercial applications of these materials are in use.

Special equipment is required to spray

these non-solvent coatings because of the highly reactive, essentially zero pot of the components when combined and because of the heavy reinforcement required to achieve the desired coating

properties.

In the case of the polyester based compounds, a free radical polymeriza-tion occurs between resin-catalyst and resin-promoter. Proportioning and mix-ing are not critical. A unitized, dual gun-chopper simultaneously sprays liquid and reinforcement. Conventional pressure pots supply the two liquids in sufficiently accurate volumetric propor-

**Epoxy Based Compounds** 

The second coating, based on an epoxy resin, is much thinner than the polyester based coating and is recommended for a minimum of 8 mils and a maximum of 30 mils. This thickness is sufficient to provide chemical resistance needed for the variety of exposure confidence of the coating that the second coating the secon ditions encountered with corrosive fumes and immersions

The epoxy based compounds are addition reaction materials. More exact proportioning and thorough mixing are required than for polyesters. The resin and co-reactant are not mixable in air. In fact, they tend to separate when combined initially. Therefore, a specially designed mixing chamber is required to mix the two components just before

spraying.

The pigment reinforcement is not dispensable by a third spray head to com-bine with the liquid stream. These fine pigment particles must be thoroughly wet and dispersed in the resin by a rather critical pre-process to achieve the desired spray characteristics. Where the polyester liquids are relatively unfilled and fluid (around 100 to 1500 cps), the compounded epoxies are extremely vis-cous (80,000 to 150,000 cps) at room temperature. Therefore, special positive displacement dual pumps with accuraries of one percent of total volume are necessary to proportion and deliver the epoxy compounds to the mixing cham-ber and spray head. Also, at critical points in the delivery, heat must be used to achieve the required mixing and flow characteristics.

This non-solvent epoxy coating, applied with equipment such as that shown in Figure 4, has outstanding impermea-bility to gases and liquids. The permeation rate for CO2 gas at 70 F through a single coat on concrete is less than 0.01 cm<sup>3</sup> (STP) cm<sup>2</sup> per 24 hours for a CO<sub>2</sub> pressure of one atmosphere applied to the face of the coating. This figure is over 10 times lower than the permeation rate for concrete coated with two coats of alkyd resin varnish and two

coats of aluminum paint.

When applied, this epoxy coating has virtually no shrinkage. Wet and dry

(Continued on Page 40)

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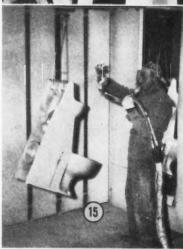
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# Polyester and **Epoxy Based** Non-Solvent Coatings





(Continued From Page 38)

(Continued From Page 38) film thickness is the same. A conventional epoxy reactive solvent system, containing 35 percent solids content by volume, will shrink to about 1.6 mils dry film thickness for each 4-mil wet coat. This implies that the non-solvent epoxy will give a service film thickness 2½ times that of the solvent type for an equal volume applied. Furthermore, this shrinkage, plus the characteristic of most liquids to flow away from sharp points and edges, causes critical areas points and edges, causes critical areas to be exposed.

Even six coats of a solvent system will have voids and pinholes due to solvent evaporation. An example of this pinholing is shown on a steel irrigation control gate coated with a six-coat vinyl system in Figure 5. Rust nodules and deep pitting can be seen. This gate has been coated with a single coat of solventless, reacted epoxy based coating and to date has shown no visible penerative fitter. tration after 28 months' service. (See Figure 6.)

Comparative data are given in Table 1 to show the superiority of the non-solvent system in immersions of exact

Figure 13—Heavy single coat of reactive epoxy system is being applied to the 191/2-inch diameter, 31 foot long hollow steel propeller shaft on a Navy destroyer. The shaft is subjected to salt water corrosion, erosion and electrolysis. Figure 14—A 30-inch diameter cement composition pipe lined with non-solvent coating to resist hot transformer oil. Figure 15-Cast aluminum plumbing fixture designed primarily for institutional use is being coated with a reactive resin system. No failures occurred after 23 months' service. A high percentage of coating failures was experienced within one year when a multi-coat solvent epoxy system was used.

or similar nature to those of the solvent system. The solvent system had severe to medium blisters in 5 percent sulfuric acid in only three weeks; the non-solvent system was unaffected after six months in both 5 percent and 75 percent solu-tions. This is dramatic evidence of the superior sealing and void-free characteristics of the non-solvent coatings. A comparison of the water resistance of the two systems also show the superi-ority of the non-solvent systems.

Another basic difference between non-solvent coatings and conventional systems is film thickness achievable on vertical surfaces without sagging in a one-coat application. With the non-solvent systems, 10 to 30 mil films are being applied on vertical surfaces with no primer required.

Application rate and number of men required to apply this single coat system are comparable to conventional solvent systems. Surface preparation, staging and other application costs are considered to be application to the systems. ered to be equal to those of other systems. However, by this non-solvent method, from 8 to 20 mils can be applied in one coat with no film shrinkage due to solvent loss.

Comparison of Shrinkage Rates

On the basis of shrinkage alone, substantial economies are realized with the non-solvent systems in comparison with conventional solvent amine-cured epoxy coatings of 8 mils thickness or more.

For a comparison of shrinkage rates, a solvent epoxy system was selected by the following criteria: (a) that it be at least of equal quality in raw materials with non-solvent coating, (b) that it is one of the best of its class being sold commercially and (c) that, in its class (solid epoxy, cut to liquid by solvent),

(Continued on Page 42)

TABLE 1—Chemical Resistance of Epoxy Coatings (Six Months' Continuous Immersion Tests; Samples on Sandblasted Steel Coupons)

Agent	Solvent-Free Epoxy 10-20 mils, 1 Coat	Solvent Epoxy 6-7 mils, 4 Coats
JP-4	U	U
Aviation Gas	U	U
Water 38°C	U	F-Sm Bl-1 month
Water 88°C	U	Not tested
Water Boiling	Not tested	Sev Med Bl-1 week
C Cl	U	U
NaCl O 16 Percent	U	Not tested
Formaldehyde 37 Percent	U	Sev micro Bl-2 months Failure 4 months
NaOH 20 Percent	Not tested	U
NaOH 50 Percent	U	Not tested
NH4OH 28 Percent	Not tested	Med Bl-3 weeks
NH4NO3 65 Percent NH3 21 Percent	U	Not tested
H <sub>2</sub> SO <sub>4</sub> 75 Percent	U	Not tested
H <sub>2</sub> SO <sub>4</sub> 50 Percent	Not tested	Sev micro Bl-2 months Failure 5 months
H <sub>2</sub> SO <sub>4</sub> 5 Percent	U	Sev med Bl-3 weeks
Sour Crude Oil	U	U
Fatty Acids	U	U
HCl 37 Percent	U	Not tested
HCl 15 Percent	U	U-3 months, F-5 months

unaffec failed. -severe. -blisters. -small.

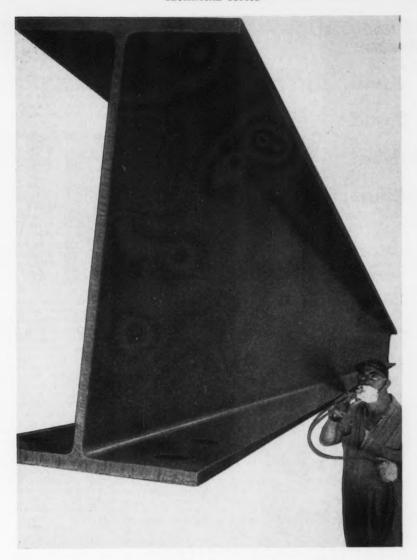
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# All the advantages of hot-dip galvanizing PLUS job-site application with CARBO ZINC 11



INORGANIC ZINC COATING is rapidly gaining recognition as the ultimate for basic protection of steel. For example, a large Gulf area chemical plant now under construction specified zinc—both hot-dip galvanizing and Carbo Zinc 11 inorganic zinc coating. Both methods are equal in performance and galvanic protection—the choice is a matter of economics.

HOT-DIP GALVANIZING is generally best for small pieces and irregular shapes: handrails, angles, floor gratings, ladders, etc.

CARBO ZINC 11 is best where these exclusive advantages count:

- Application can be made on the job-site.
- Old steel, in place, can be galvanically protected.
- Repairs can be made in the field.
- · Field welding can be touched up.
- Only one side need be coated, such as storage tanks.
- All sizes and shapes can be coated.

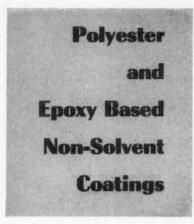
EASY TO APPLY with spray or brush in any kind of weather. Water insoluble in 20 minutes. WRITE for analysis of costs "When to Hot-Dip Galvanize—and When to Use Carbo Zinc 11."

Maintenance Coatings with Experience...



32-A Hanley Industrial Ct. . St. Louis 17, Mo.

Vol. 17



(Continued From Page 40)

it has highest solids content of those coatings that can be sprayed by conventional equipment.

The system selected for this com-parison contained 48 percent by weight and 65 percent by volume volatile solvents. Experience has shown that this film will shrink to a dry film thickness of 38 to 40 percent of its original wet film thickness.

With this solvent epoxy system, the heaviest wet film which can be applied practically is 4 mils per coat when operating at an efficient spray rate. Five coats for optimum performance of this coating are recommended (two primer and three top coats), giving a final optimum thickness of 8 mils.

With 8 mils as the thickness constant

for comparing solvent and non-solvent epoxy coatings, the following points were calculated:

1. One gallon of any liquid will cover about 200 square feet of smooth surface, 8 mils thick, wet film.

2. One gallon solvent system after shrinkage to 40 percent in drying will cover about 80 square feet with 8 mils dry film in five coats

3. One gallon non-solvent epoxy based

ompound will cover 200 square feet with 8 mils dry film in one coat. The above points were calculated with the assumption that there would be no losses for overspray with either system.

### Cost Comparisons Made

Material cost only of the non-solvent coating at 8 mils, assuming a factor of 20 percent loss due to overspray, is 10 to 12 cents per square foot. For the solvent epoxy system, material cost is 12½ to 15 cents per square foot. For film thickness of 12 mils, unachievable in any practical manner with the solvent epoxies but often recommended for the non-solvent type for continuous immersion service, material cost

would be 13 to 16 cents per square foot.

Even more savings are derived from the fact that the non-solvent system required the labor of only one coat; the solvent system required the labor of five with the recommendation of time consuming cures between each coat.

### Examples of Non-Solvent Systems

Examples of non-solvent epoxy applications are shown in Figures 7 through 15. These include exterior and interior coatings on truck tanks, ship hull coatings, protection for wine processing tanks, coatings on equipment for filling beer cans in a brewery, exterior and interior coatings for pipe, and finishes

interior coatings for pipe, and misnes for plumbing fixtures.

The wine fermenting tank shown in Figure 11 was lined with the non-solvent epoxy resin system for the following special requirements: (1) permanent adhesion to the metal, (2) un-affected by organic acids and alcohol in affected by organic acids and alcohol in wine, (3) impacts no taste, odor or color the fermenting product, (4) easily cleaned with hot water, steam and soda ash or chlorine solutions yet remains unaffected by them, (5) economical to apply to provide long-term protection from contamination of product by rust and scale with little maintenance needed and (6) resists the abrasion and wear on sides and bottoms of the tanks caused by agitation of the fermentation

This wine tank coating was sprayed in one coat without primer to the wine company's specifications of 15-mil minimum, 20-mil maximum.

Other applications include lining and coating of pipe and tanks for handling jet fuel and caustic soda. As a resistant, decorative coating, these non-solvent systems can be used to protect showers, bathtubs, washers, aluminum steel and plywood.

#### Summary

These non-solvent coatings have negligible or zero shrinkage and are applied in non-porous and chemically resistant heavy coats which can provide rein-forcement with structural advantages. These accomplishments obviously could not be made with materials which shrink to give voids and inconsistancies often found in conventional coatings using carrier solvents.

The danger of explosion and/or fire

during application has been greatly reduced. Application of films developed in recent years has been curtailed in many cases because of the explosion hazards which are especially critical during spray operations in confined areas such as tanks.

This article is not intended to imply that non-solvent reactive coatings should generally replace solvent type coatings. For any application where performance of the solvent type systems will suffice,

Both polyester based and epoxy based non-solvent coatings should be used.

Both polyester based and epoxy based non-solvent coatings should be considered where corrosion control cannot be effectively achieved by solvent coatings and/or other protective measures.

Where optimum surface preparation cannot be provided practically, such as sandblasting to white metal, non-solvent coatings offer more protection than the thinner solvent coatings because of the former's sealing characteristics. How-ever, prescribed surface preparation is necessary to achieve optimum performance with the non-solvent systems.

Special multi-component equipment is

required to apply these reactive coatings. Spray application to a variety of surfaces has proved to be practical.

These reactive coatings are not recom-

mended for corrosive conditions without pre-determining their performance in a particular environment.

The two coatings discussed in this article are only two of many coatings which probably will conform to the re-active principles. New chemical bases and methods undoubtedly will be developed for other coating systems in the non-solvent class.

### Acknowledgment

Valuable assistance of R. D. Harline and W. R. Callaway of Hodges Chemicals Company and R. Burkel of Chemical Process Company is gratefully acknowledged.

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See Nace News Section beginning on Page 63 for information concerning the 1961 NACE Region Conference technical programs.

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# REPUBLIC ELECTRUNITE "DEKORON-COATED" E.M.T. RESISTS SULPHUR DIOXIDE FUMES

In the sulphur dioxide atmosphere of the Anheuser-Busch, Inc., starch-making plant, all conduit is being replaced with "DEKORON-COATED" Electrical Metallic Tubing to cut maintenance and replacement problems in the electrical system.

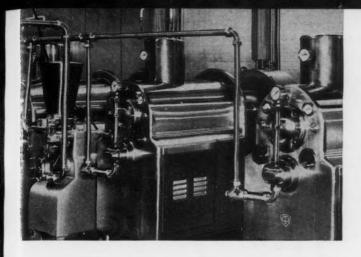
Sulphur dioxide, a basic ingredient of the starch manufacturing process, eats away galvanized conduit in less than four months. "Dekoron-coated" E.M.T. replacements have been in service up to twelve years under the same conditions and are still undamaged and serviceable.

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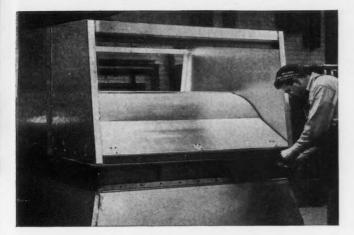
For complete information on corrosion-resistant "DEKORON-COATED" E.M.T., call your Republic representative or send the coupon below.



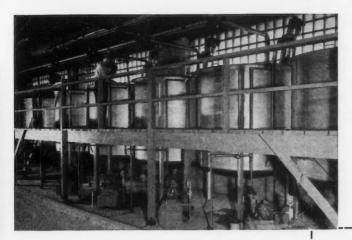
SULPHUR DIQXIDE ATMOSPHERE eats away I-beam in Anheuser-Busch starch plant, while "DEKORON-COATED" E.M.T. remains unharmed.



REPUBLIC ELECTRUNITE STAINLESS STEEL TUBING offers resistance to a wide range of corrosion, physical damage, temperature, and pressure extremes in corrosive and sanitary applications. Meets ASTM or ASME requirements. Available in tubing sizes from 1/4" through 5" O.D. Uniform wall thickness and diameter. Send coupon for full data.



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Because of this superior performance, one might expect a Fluoroflex system to be more expensive than it is. However, on an installed cost basis, Fluoroflex-lined steel piping is today comparable with or cheaper than pressurepiping of several high-nickel alloys.

As a result leading engineering-construction firms now use Fluoroflex rigid piping systems and flexible components in new plant construction to stop corrosion or contamination and to reduce erection costs.

■ Fluoroflex preflanged piping eliminates cutting chamfering, cleaning, welding, scale, flux, weld spatter and annealing—minimizes the need for gaskets, hangers, supports, and anchors as required for non-metallic piping.

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# RECORD and REPORT

# Manufacturers Rush to Develop Smog Burners

# California Hopes To Stop Auto Smog With Devices by '65

Upon exposure to the sun's ultraviolet rays, hydrocarbons that escape combustion n automobile engines turn into smog. Roughly, 70-80 percent of the unburned hydrocarbons are discharged through the hailpipe, 10-20 percent from the crankcase 70-80 percent of the unburned and the remainder evaporate in the tank and carburetor.

California, especially Los Angeles, has been plagued by automotive smog for many years, but relief is in sight. Devices that burn these fugitive hydrocarbons are expected to end California's major smog problem by 1965.

Exhaust burners will be mandatory on all new cars purchased in California in one year and on all cars in three years after at least two burners are approved by California's Motor Vehicle Pollution Control Board. To be acceptable these devices must reduce current average motor vehicle hydrocarbon emission 80 percent and carbon monoxide by 60 percent.

Two Types Are Promising

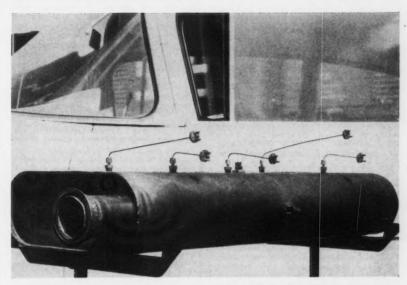
Two Types Are Promising
Two types of exhaust burners appear
promising. One, the direct flame afterburner, burns hydrocarbons at about
1500 F. The other, usually called a catalyst burner, with the aid of chemicals,
burns hydrocarbons at temperatures ranging from 800-1500 F

Blowby devices that capture crank-Blowby devices that capture crank-case fumes and carry them back into the carbureter where they are burned were factory installed on all new cars destined for sale in California in 1961, although these devices were not re-quired by law. However, the Los An-geles County Board of Supervisors is urging that California make mandatory the installation on all new cars a 100 the installation on all new cars a 100 percent effective blowby device. The presently installed 80 percent effective device on a new car sells for about \$5. With the addition of a piece of tubing and two inexpensive fittings to carry fumes from the valve cover to the car-buretor air intake, the device would be 100 percent effective, the board reports.

Practicing what it preaches, Los Angeles County's fleet of 3500 cars is being equipped with 100 percent effective blowby devices.

None Yet Approved
Manufacturers have rushed development and testing of anti-smog afterburners and catalysts but California has burners and catalysts but California has yet to approve any for statewide installation. In fact, according to the Wall Street Journal of June 29, 1961, only one device, an anti-smog auto muffler developed by Oxy-Catalyst, Inc., has been accepted for testing by California. The article added, however, that testing applications pending included these of applications pending included those of

(Continued on Page 48)



EXHAUST BURNER made of Allegheny Ludlum Steel Corporation's new stainless steel MF-1 is one of many such devices recently developed to burn hydrocarbons that escape combustion in automobile engines. Upon exposure to sunlight, hydrocarbons form smog. After two such devices have been approved by California, they will be mandatory on all cars in California within three years.

### Manufacturers of Exhaust Burners

Company	Type of Device	Remarks	
Calumet & Hecla, Inc.	Unknown		
Chromalloy Corporation	Afterburner	About the size of an 8-cup coffee pot	
W. R. Grace & Co., Inc.	Catalytic muffler	Successfully road tested for 25,000 miles	
Holley Carburetor Co.	Afterburner		
McAlester Aircraft	Unknown		
Oxy-Catalyst, Inc.	Catalytic Muffler	Approved for testing by California	
Standard Products Co.	Unknown		
Thompson Ramo Wooldridge, Inc.	Afterburner	Being developed for production by Chrysler Corp.	
Union Carbide Corp.	Catalytic burner	To be tested by auto producers	
Universal Oil Products Company	Catalytic burner		

### **Smog Burners**

(Continued From Page 47)

Chromalloy Corporation, W. R. Grace & Co., Standard Products Co., Calumet & Hecla, Inc., McAlester Aircraft, Inc., Arvin Industries, Inc., Universal Oil Products Co. and the Morris-Williams venture, a private invention. Fourteen testing applications at that time had been rejected.

Chromalloy Corporation's device, called a "Smog Burner," is a combustion chamber fitted to the engine either at the exhaust manifold or at the entrance to the muffler. About the size of an 8-cup coffee percolator, this device has a by-pass valve which allows a portion of exhaust gas to short circuit the burner during those periods of operation when flow rates are high and few hydrocarbons are unused. Chromalloy says the device is small enough to fit in engine compartments or mufflers, requires no blowers, does not burn additional gasoline, has only one moving part, has a potential service life of about 50,000 miles and is not susceptible to a reduction in effectiveness through accumulation of lead fuel additives.

Companies Merge Interests Universal Oil Products and Arvin In-

Universal Oil Products and Arvin Industries, both working on anti-smog devices, combined forces to exchange technical information and Arvin, if it wishes, can market a muffler using the catalyst Universal Oil developed. Universal Oil has a catalytic muffler also, according to an article in Chemical & Engineering News, October 17, 1960, issue.

A combination direct combustioncatalytic oxidation unit has been devel-



FOR SOME SELECTED AREAS

oped by Union Carbide Corporation. This unit burns 80 to 90 percent of hydrocarbons and carbon monoxide, Union Carbide says. Designed to take advantage of engine heat, the unit employs special catalysts, operates at elevated temperatures and has minimum bulk.

W. R. Grace & Company's Davison Chemical Division is reported to have developed a catalytic muffler. According to an article in Business Week, May 13, 1961, "A prototype built by Los Angeles' Norris-Thermador Corporation has been successfully road tested for more than 25,000 miles."

Altogether, about 40 manufacturers already have or plan to have anti-smog devices to submit to California for approval. The general price range probably will be somewhere between \$75 and \$175.

Armco Develops New Alloy

Although manufacturers have not revealed any significant information on materials being used to construct these devices, Armco Steel Corporation reports it has developed a new alloy steel specifically for anti-smog devices. This new grade is nominally 21 Cr, 6 Ni and 9 Mn, a modification of an alloy steel developed by Armco for exhaust valves in high compression engines designed to withstand temperatures in the 1200-1400 F range. Armco says test of initial heats at Armco laboratories and by five manufacturers have proved the alloy's strength at high temperatures and its resistance to lead salt attack from exhaust gases. Also, the alloy can be worked and fabricated using conventional techniques and equipment. Armco predicts its new 21-6-9 will be used extensively in both catalytic and afterburner devices for inner containers, catalyst supports, heat exchange parts, baffles and support and other parts where temperatures reach or exceed 1650 F.

Allegheny Ludlum Steel Corporation says its new stainless steel, MF-1, developed for use in automotive mufflers, is being tested for use in exhaust burners.

Auto Makers Warned

Auto makers have been warned that if they do not make the inexpensive blowby devices standard equipment, they will be forced to by law. In August, Secretary of Health, Education and Welfare Abraham Ribicoff set the deadline to begin with 1964 models, according to an article appearing in the August 14, 1961, issue of Chemical & Engineering News. Already the General Services Administration has specified blowby devices for the 12,000 or so vehicles it purchases each year.

In Philadelphia, the Philadelphia Bulletin of March 10, 1961, reports, plans are under way to install blowby devices on all city-owned automobiles. Thirty-seven percent of hydrocarbons in Philadelphia are private car products, 5 percent commercial auto products, according to Raymond Smith, head of the Philadelphia Health Department's air pollution control section which estimates approximately 1350 tons of air pollutants are released in Philadelphia daily.

The December, 1960, Los Angeles County Air Pollution Control District Report stated that the District of Columbia had requesed blowby devices be installed on all 1962 models delivered in the area and that Washington officials were asking that Maryland and Virginia to do likewise.

# Los Angeles Keeps Close Watch on Air Pollution Sources

The wide scope of air pollution controls in effect in Los Angeles County is indicated vividly by the August, 1961, report of the County Air Pollution Control District, 434 S. San Pedro Street, Los Angles 13, Cal. Briefly, here are some of the controls in force or in sight to prevent air pollution disasters:

Permits to produce phthalic anhydride for the first time in Los Angeles County have been issued to Reichhold Chemical Company after a \$40,000 direct fired afterburner proved successful in controlling excessive combusiton contaminants and opacity of emissions. Previously a scrubber and catalytic afterburner failed to reduce emissions sufficiently to meet APCD requirements.

Rule 63 limiting to Bromine No. 30 the olefin content of gasoline sold in the county was not violated at any of 540 pumps tested during June, the APCD Enforcement Division reported.

Strict enforcement against excessive smoke from diesel trucks has resulted in more than 8000 citations against truck owners and operators since 1954. Almost 7000 smoking passenger vehicles were cited during the same period.

Sulfur and nitrogen compounds will be reduced in exhausts of diesel vehicles using fuel from a \$2,200,000 unifining unit for which a permit to operate was recently granted Union Oil Company. The unit removes these substances from the fuel.

Atmosphere lead concentrations will be measured during the next year in four areas of the Los Angeles Basin as part of a three-city study of the U. S. Public Health Service. Cincinnati and Philadelphia are the other cities. These studies are the outgrowth of a recent move to increase the amount of tetraethyl lead in gasoline.

Ninety-six percent of daily emission of carbon monoxide comes from motor vehicles, about 9,050 tons. The installation of waste heat boilers on all fluid catalytic regenerator units in major refineries in Los Angeles County has eliminated 1,582 tons per day.

The report comments on a program to clean up air pollution in the steel industry in Allegheny County, which surrounds Pittsburgh, Pa, by 1971 when all open hearth furnaces will have cleaners. A similar program was completed in Los Angeles County in 1951.

See Page 18 for Staff Feature on Auto Mufflers 1. 17

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### **Technical Topics** Scheduled for November

Laboratory and Field Tests on Titanium for Oil Field Pump and Valve Parts

Accelerated Testing for Resistance to Erosion-Corrosion for Appliance Applications

Laboratory and Field Data on Chlorinated Polyether Coatings Produced by Water Suspension System

### New Method of Producing Metallic Coatings Found

A new method of producing metallic coatings has been developed at Armour Research Foundation, 10 W. 35th Street, Chicago 16, Ill., according to Armour's Industrial Research Newsletter.

Spraying metal surface with metal oxide, then reducing with hydrogen is the technique, called reduced-oxide coating. Application of oxide is made by Flame Ceramics process developed at the foundation. Studies of the coat-

ing utilizing NiO indicate layer of nickel adjacent to steel converts to dense, continuous, pore-free metal. Technique should apply to any oxide that can be readily reduced, including copper, nickel, tungsten, iron, molybdenum and their alloys, the Newsletter reports.

### Professional Engineers to Meet in Roanoke Oct. 19

The National Society of Professional Engineers will hold its Fall Meeting at Hotel Roanoke in Roanoke, Virginia, October 19-21

### POSITIONS WANTED and AVAILABLE

Active and Junior NACE members and companies seeking salaried employees may run two consecutive advertisements annually without charge under this heading, not over 35 words set in 8 point type. Advertisements to other specifications will be charged for at \$12.50 a column inch.

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### **Positions Available**

Wanted: Sales engineer to sell and service anodes for cathodic protection. Experience in the field desirable. Nationally known company with headquarters in Midwest. Send resume of education and experience. CORROSION, Box

Sales Manager and/or Corrosion Engineer. 15 years experience in the corrosion field. Spe-cialized during the past 6 years as sales man-ager for firms dealing with pipeline coatings and cathodic protection. Excellent record. Desire West Coast, CORROSION, Box 61-23.

Sales Engineers . . . To call on steamship lines, shipyards, ship owners to represent a complete line of cathodic anti-corrosion systems. These systems are technologically very strong and have many years of development, field testing, and use behind them. Send resume, including area covered to CORROSION, Box 61-22.

### **Positions Wanted**

Corrosion Supervisor with major oil company and 12 years' corrosion experience (pipelines, gas and LPG plant, production, marine craft) desires relocation Arizona, California. Sales or engineering. Top references. 1301 Thurber Place, Tucson, Ariz.

Chemist B. S., Master's courses completed metallurgy. Worked with, studied corrosion. Same company: Laboratory, development metal tubing 6 years; supervisor photoetching department 5 years, now closed. 3, married, family. Prefer Northern Third U. S. CORROSION, Box

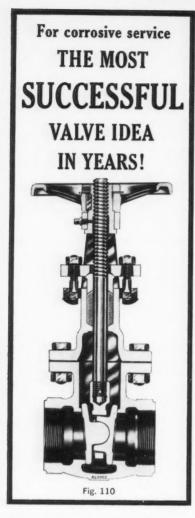
Corrosion Engineer—BEE, 12 years' experience in oil, mining & consulting engineering opera-tions at engineering and managerial levels. Desire supervisory position with growth potential.

Resume on request. CORROSION, Box 61-19.

Engineer B.S.E.E., age 35, 11 years' experience in all phases of production, process plant, pipeline and gas distribution corrosion control. Desires responsible position with oil, gas or pipecompany. Will consider relocating. COR-ROSION, Box 61-18.

The 1961 North Central Region Conference will be October 9-11, Chase Park Plaza Hotel, St. Louis, Missouri.

The 1961 South Central Region Conference and Exhibition will be October 24-27, Shamrock Hilton Hotel, Houston,



This Aloyco Valve design was the pioneer! It's also the most imitated valve design in years. It met with immediate success in the chemical and petroleum fields and has found constantly growing acceptance throughout the processing industry for over a quarter of a century. Valve Fig. 110 (screwed), Fig. 116 (butt welding), Fig. 114 (socket welding), Fig. 111 (flanged) feature double disc ball and socket wedges with free floating, self-adjusting disc position which insures tight closure. For more information about the lasting value of Aloyco Stainless Steel Valves in the handling of corrosive fluids-write today. Ask about the extraordinary range of alloys available to solve your particular problem. Alloy Steel Products Company, 1301 West Elizabeth Avenue, Linden, New Jersey.



ALLOY STEEL PRODUCTS COMPANY

### Zinc Institute Looks for **Better Zinc Auto Paints**

Improved zinc paints, with better adhesion, flexibility and welding characteristics than these paints now have, are the goal of research in England sponsored by the American Zinc In-stitute, 292 Madison Avenue, New York

17, N. Y.
Finding better paints for priming automobile underbodies is the first concern of this research. Zinc paints already are finding extensive use in the United States to combat automobile corrosion, particu-larly significant since the adoption of unitized auto bodies and the use of corrosive salts, cinders and chemicals to improve traction on icy roads, the institute reports.

Zinc paints for structural steelwork and marine applications also are scheduled for development under the program. Most of the research in England will be carried on in laboratories of Imperial Smeltering Corporation, Ltd., at Avonmouth, with assistance of Amalgamated Oxides (1939), Ltd., of Dartford and Durham Chemicals, Ltd., of

### New Electric Burner **Boosts Natural Gas** Flames to 6000 F

An electric burner capable of boosting ordinary fuel-oxidant flames to 6000 F for chemical and metallurgical processes is under development by Arthur D. Little, Inc., 30 Memorial Drive, Cambridge 42 Mass. The burner superimposes on the flame electrical energy from a low current, high voltage, alternating current discharge.

The burner can be used with any commercially available fuel—natural gas, fuel oil, powdered coal or hydrogen with oxidizers from air or oxygen to fluorine or exotic mixtures, ADL says.

Natural gas flames have been boosted by the burner to heat that melts tanta-lum which has a melt point of 5400 F. The addition of electric power equal to one-half the chemical combustion power at an optimum air-fuel ratio boosts the gas specific enthalpy (heat content) from 1100 BTU/pound to 1600 BTU/pound have been obtained with fuel rich flames and still higher figures are expected from increased electrical power, ADL

The high temperature, high specific enthalpy product of the burner is a potential heat source when either rapid, temperature heating or an localized heat source above 3000 F is desired, ADL says. Impingement heating for such processes as cutting, welding, spalling, scarfing and drilling is one application of the burner. Heating of materials to a very high temperature by feeding them directly into the flame is a logical use for the new burner, especially when organic materials are used because slower methods would destroy the molecules and form carbon and various oxides, ADL reports.

Both radiant heating, as in open hearth steel furnaces, and indirect heating could employ the new burner if refractory materials for suitably high temperatures can be used economically. Fluidized bed processes and submerged

combustion techniques are two other applications ADL has found promising

Development work to date, ADL says, has used an electrical discharge from a 60-cycle alternating current

from a 60-cycle alternating current power supply at discharge potentials to 2000 volts and current to 12 amperes. The burner, called the Combex-ADL Burner, is a patented invention of Bela Karlovitz of Combustion and Explo-sives Research Inc., Pittsburgh, Pa.

### **BOOK NEWS**

Publications 1904-1960. University of Illinois Engineering Experiment Station. 43 pages, 6x9 inches, paper. Vol. 58, No. 79, July, 1961, University of Illinois Bulletin. 49 Administration Bldg. (West), Urban, Ill. Availability not indicated. not indicated.

Bulletins are listed chronologically, with notations of availability and price. There are 459 so listed. Sixty-eight circulars are listed as are 61 reprints.

There is an alphabetical subject index which does not include a corrosion cat-

Transactions of the Symposium on Electrode Processes. Ernest Yeager, editor 374 pages 81% x 11 inches Electrode Processes. Ernest Yeager, editor. 374 pages, 8½ x 11 inches, cloth, July 21, 1961. John Wiley & Sons, Inc., 440 Avenue South, New York 16, N. Y. Per copy \$20.

Consists of 18 papers presented during a symposium of the Theoretical Elec-trochemistry Division, The Electrochemical Society, Philadelphia, May 4, 1959. Paul Delahay, Louisiana State University, Baton Rouge, was chairman.

Among those published are papers concerning adsorption of ions at the metal-solution interface, the double layer and the rate of electrode processes, measurement of the kinetic parameter of yery rapid metal electrode reactions

There is an extensive alphabetical subject index.

Developments in Industrial Biology. Vol. 2. Saul Rich, Editor. June, 1961. 306 pages, 6½ x 9% inches, cloth. Consultant's Bureau Enterprises, Inc., 227 W. 17th St., New York 11, N. Y. Per copy; Domestic \$9; foreign, \$10.50.

Proceedings of the 17th General Meeting of the Society for Industrial Micro-biology, August 28-September 1, 1960, Oklahoma State University, Stillwater. Stillwater.

Twenty-six articles divided into the following topical subdivisions are pre-sented: Petroleum microbiology, deter-ioration of materials, non-medical astopical subdivisions are prepects of antibiotics, methodology in the fermentation industry, plus a section of contributed papers. Of special significance to corrosion workers and men concerned with ma-

terials protection are four papers on petroleum microbiology and six papers petroleum microphology and sa per-on materials deteriation. In this latter category, are "Microbiological Deter-ioriation of Plasticizers," and "Biode-ioriation of Plasticizers," and "Biodegradibility of Alkylbenzene Sulfates, among others.

among others.

Among the contributed papers significant to corrosion workers are "Microbiological Sludge in Jet Aircraft Fuel," and "Resistance of Organic Materials to Marine Bacterial Attack."

The book is liberally illustrated, has numerous tabulated data and an accumulative index to Volumes Levid.

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### Lab at U. of California Synthesizes Element 103

Element 103 has been synthesized in the Lawrence Radiation Laboratory of University of California in Berkeley. Three-millionths of a gram of californ-ium was bombarded with boron-10 or boron-11 nuclei having energies of about 70,000,000 electron volts. Half-life of new element is about eight seconds. This information was published in the Industrial Research Newsletter of Armour Research Foundation, which attributes the source to Science Service, 1719 N. Street, N. W., Washington 6, D. C.

Element 103 closes out the actinide series of elements, according to the re-port. Element 104 should have properties unlike other synthetic elements.

probably resembling hafnium and zir-conium since it falls directly under them in the periodic table. Atomic weight of Element 103 is thought to be no more than 257.

### **AEC** to Head Development Of Low Temperature Reactor

A low temperature process heat demonstration reactor is on the Atomic Energy Commission's agenda for development by 1965. The purpose is to provide technical and economic data on the practicality of such reactors in high fuel cost areas.

Possible applications of such reactors would be supplying large amounts of heat required in operations such as chemical processing, production of paper and pulp products and conversion of

saline water to fresh water.

In response to the AEC's invitation to participate in the development of the reactor, four paper manufacturers have expressed interest.

# Corrosion Minor to Aluminum Drill Stem During 10-Month Test

Insignificant corrosion damage has been suffered by 4.5-inch aluminum drill stem during the drilling of over 100,000 feet of hole in Central Texas oil wells during the past 10 months. Reynolds Metals Co. and Reed Roller Bit Company personnel reported this and other significant service information on the drill stem used on Shell Oil Com-pany wells at a noon luncheon-press conference at the Houston Club, August

R. S. Dalrymple, Reynolds corrosion engineer, said that except for corrosion erosion in some joints resulting from turbulence in drilling mud around a poor joint design, no measurable corrosion damage of any kind can be detected on the stem. About 20 percent of the string was damaged by corrosion-erosion before polybischloromethyl oxe-tane (Penton) boots were inserted into the joints to reduce the turbulence.

The joint has been redesigned since and the turbulence eliminated. None of the tubing was damaged sufficiently to cause it to be removed and tensile tests showed the drill stem to be better than equivalent sized steel drill stem.

### Other Corrosion Data

Mr. Dalrymple also made the following points

1. In laboratory tests aluminum has shown no susceptibility to damage by hydrogen sulfide.

2. No galvanic corrosion has been detected inside or outside the drill stem in the vicinity of the joints or anywhere

No inhibitors were used in the drilling muds during the tests and no special provisions were made respecting

4. Laboratory tests of aluminum in all kinds of drilling muds have produced no significant attacks on aluminum.
5. Slip marks at joints have had no

5. Sup marks at joints have had no significant effect on strength and have not been sites of corrosion damage.
6. The drill stem material is not exotic and has had no special tempering

or alloving.

### Economic Advantage Seen

In other discussions it was also brought out that 4 or 5 mils of a proprietary solvent-dispersed epoxy coating was used inside some of the joints experimentally. Reynolds is not yet ready to market the stem, but expects to accumulate experience in several hundreds of thousands of feet of hole be-

fore offering the material generally. On the basis of preliminary data available so far, there is a decided economic advantage in using the aluminum drill stem over an equivalent steel stem, a

spokesman said. Most of the 85,000 channel miles of the United State's television facilities are

equipped for color transmission.



### **HOW 116 OIL WELLS WERE** PROTECTED FROM CORROSION

Several leaks, caused by external casing corrosion, had already occurred in this Permian Basin field of 116 wells. No previous attempt had been made to stop the corrosion.

To determine the current required for protection, CSI spot checked 25 of the wells—using the "log current potential method" developed and patented by a CSI engineer.

It was found that a maximum of 6 amperes was sufficient to stop corrosion. However, it was decided to use 8-ampere rectifiers as the current source so that there would be a reserve to meet changing requirements caused by weather. In some instances it was found advisable to install 16- and 24-ampere rectifiers to protect 2 or 3 wells in groups.

CSI's experienced crews handled the complete installation, furnishing the rectifiers, all other necessary materials and equipment, plus a full report.

You will find CSI an economical, reliable source for engineering and installation services; and for cathodic protection supplies including Dow magnesium anodes.



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### Low Conductivity Water Achieved by Ion Exclusion

An ultra low conductivity water schieved by electrophoretic ion-exclusion achieved by electrophoretic ion-exclusion technique is reported in the Industrial Research Newsletter of Armour Research Foundation, which attributes the ource as the National Bureau of Standards' Office of Technical Information, U. S. Department of Commerce, Washington 25, D. C.

Resulting water is said to approach ultimate purity more closely than any water previously reported, its electrical conductivity of 0.039 x 10-8 ohm-1 at 18 C indicating residual ion content equival-

indicating residual ion content equival-ent to sodium chloride concentration of one part per billion.

Purification apparatus also was designed to circulate purified water continuously through the electric field; this circulation immediately removes

any contaminating ions that originate from walls of apparatus.

High density polyethylene, platinum and borosilicate glass exposed to steam for a number of hours just before purification also were found suitable for ion-exclusion technique.

### German Standards Printed in English in July, 1961

German standards published in English during July, 1961, include the following items of interest to corrosion

DIN UDC 621-5: 629.12 Regulation, servicing for shipbuilding: 87341, Installation principles (October, 1955); 87342, Examples of installations (October, 1955)

ber, 1955).

UDC 621.646.6: 629.12 Taps for ship-building: 87003, Sheet 1, Non-ferrous metal cocks and taps; drain taps,

screwed male, lockable type, nominal size R ½ to R 1 inch, nominal pressure rating 6, list of sizes and parts list (May, 1955).

UDC 621.791 Soldering, Welding: 1913, Sheet 1, Metal arc welding electrodes for joint welding (welding electrodes for going and lowellong electrodes).

trodes for joint welding (welding electrodes for plain and low alloy steels) (May, 1960).

UDC 669.2/.8 Non-ferrous metals: 1718, Copper alloys, definitions (November, 1959), 1733, Alloys for welding and brazing heavy metals and for brazing ferrous materials (June, 1944); 1734, Silver solders for heavy metals and ferrous materials (June, 1944).

UDC 678.5/.8 Plastics: 7708, Supplement Plastics, properties of test specimens from phenolic and aminoplastic moulding materials (types) (August,

moulding materials (types) (August, 1960).

These standards are available from Deutscher Normenausschuss, Uhlandstrasse 175, Berlin W 15, Germany.

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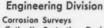
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# Plastic Props Are Used to Position Steel Rods in Concrete

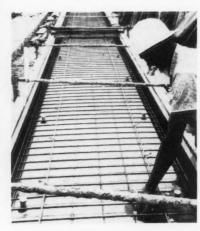


BUNDLES of continuous slab and beam bolsters are stacked for use at construction site of Kips Bay Plaza on New York City's East Side. The bolsters will be used in constructing a building identical to that in the background.

QUICK POSITIONING of reinforcement rods is possible with continuous slab and beam bolsters. Plastic legs eliminate possible galvanic coupling of rods with dissimilar metals.

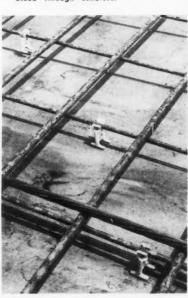


# to Eliminate Galvanic Couplings



WORKMAN snaps on plastic prop to position rods in long form used to set concrete decking for new parking floors atop New York City Port of Authority Bus Terminal, Deck beams were made by American-Marietta Company at Kenvil, N. J., and shipped to job site.

SNAP-ON PLASTIC PROPS used to support heavy steel rods during concrete setting will not support electrolytic action that causes rods to rust and bleed through concrete.



Positioning steel reinforcement rods with plastic props is a recent innovation in concrete setting. The purpose is to eliminate galvanic coupling of the rods to dissimilar metals which is sometimes the case when steel props are used, resulting in deterioration of the rods and the concrete.

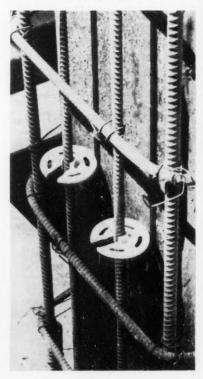
sulting in deterioration of the rods and the concrete.

As shown in the accompanying photographs, the plastic props hold heavy reinforcement rods at desired heights and spacing while the concrete is poured. They are made of high density polyethylene which is rigid tough and chemically resistant and which retains its strength during high and low temperature extremes.

Already used in many reinforced concrete constructions, the lightweight, easily installed props are available in various heights and rod sizes in three shapes: continuous slab and beam bolsters, mesh props that snap into place and spacers for holding exact clearances between reinforcing bars and form face.

form face.

The plastic props are designed and marketed by Universal Builders Supply Company, Inc., 41 East 42nd Street, New York 17, N. Y. Supplier of polyethylene is W. R. Grace & Co., Polymer Chemicals Division, 225 All-wood Road, Clifton, N. J.



PLASTIC SPACERS hold exact tolerance between reinforcing bars and concrete form face. Easily installed, the spacers are useful also for positioning pipe.

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### PERIODICALS

Journal of Chemical and Engineering Data. Quarterly. January, 1961, Vol. 6, No. 1. 160 pages, 8¼ x 11¼ inches. American Chemical Society, 1155 Sixter of the Chemical Society, 1155 Sixter of the Chemical Society. American Chemical Society, 1153 Sixteenth St. N. W., Washington 6, D. C. 4 issues: ACS members, \$9; nonmembers, \$18. Postage per year: Foreign \$1.20; Canada \$0.40; Postal Union American States \$0.30.
Divided into Part 1—Phase equilibria, molecular transport, thermodynamics and Part 2—Physical properties, evaluation of compounds and materials. Con-

tion of compounds and materials. Con-ents include heats of mixing benzene nd cyclohexane, thermodynamic aproach to measurement of hydrosco-

Application of the principal of corresponding states for polar substances; tructure and surfactance—evaluation of sicinoleyl alcohol, among others.

A symposium on lubrication under streme conditions contains 15 papers, ncluding "Frictional Properties of Some Solid Lubricant Films, Under High Load."

Periodical Monitor. Electronics and Instrumentation Section. Monthly. July, 1961, Vol. 1, No. 1. 8½ x 11 inches. 34 pages. Periodical Monitor and Abstract Service, 15 North Euclid Ave., Pasadena, Cal. Domestic U.S. and Canada, one year \$25; elsewhere \$20. Contains 385 abstracts of May, 1961 literature on electronics and instrumentation from 66 periodicals not including tation from 66 periodicals not including Corrosion. Numerous other periodicals are monitored.

Included also is a subject index and an author index. Plans for the magazine involve expanding the periodicals from which abstracts are taken, including those from foreign countries.

### Standards Group to Meet In Houston October 10-12

The 12th National Conference on Standards will be held in Houston, Texas, October 10-12. Attendance is

open to all organizations and individ-uals interested in standards work. Standardization methods that reduce production costs will be presented at this meeting sponsored by the American Standards Association. Eight sessions have been scheduled, one of which will be a review of standardization at all levels of the economy including the in-ternational field. Also on the agenda are sessions covering standards in plastics, material handling, safety, purchasing, data processing and mobile homes.
H. C. Ball of Humble Oil & Refining

Company, Baytown, Texas, is program

### Corrosion Sessions Set For Electrochemical Meet

The Electrochemical Society, Inc., 1860 Broadway, New York 23, N. Y., scheduled several corrosion sessions at its October 1-5 meetings in Detroit, Mich.

The Battery and Corrosion Divisions scheduled a joint symposium on fused salt corrosion. The Corrosion Division scheduled sessions on corrosion and inhibition in aquerous solution, high tem-perature oxidation and surface struc-ture vs. corrosion behavior.

### Galvanizers to Meet

The Galvanizers Committee holds its 44th meeting November 2-3 at the Sheraton Hotel, Philadelphia, Pa. This committee of sheet and pipe galvanizers of the steel industry is sponsored by American Zinc Institute, 292 Madison Avenue, New York 17, N. Y.

### Du Pont Gets Process to **Develop Ductile Chromium**

Development of ductile high temperature chromium alloys may be possible by using an alloying process which it recently acquired, E. I. du Pont de Nemours and Co., Wilmington, Del., reports.

Under an agreement with the Australian Government, Du Pont has sole U. S. rights to investigate the Australian process developed by the Aeortalian process developed by the Aeortalian process developed by the Aeortalian Po nautical Research Laboratories and the

Defense Standards Laboratories of the Department of Supply and to manufacture the alloys if the process is feasible.

### U.S. to Participate in Instrumentation Congress

The government plans to participate the Watchmakers and Mechanical Instrumentation Congress scheduled for March 10-13 at New York City's Commodore Hotel. The technological rush to miniature instrumentation in electronics and missiles has created a shortage of instruments craftsmen to keep up the pace.

Government bodies to participate in the congress are the Defense Department, Department of Commerce, Oceanographic, Naval Observatory, Bureau of Standards, Office of Defense Mobilization, Army's Diamond Ordnance Fuze Laboratories and the Space and Missile groups.

# it's a proved fact . .

in nine cases out of ten Standard Magnesium H-1 alloy anodes have proven more economical protection against corrosion . . .

> In the past 10 years, millions of installations have proved that Standard's H-1 alloy anode provides far better, more economical protection against corrosion.

> H-1 alloy anodes are more economical because they insure protection over a much longer period. In fact, H-1 alloy anodes have a useful life expectancy of 10 years, while other anodes may last only 5.5 years.

> Insist on Standard Magnesium H-1 alloy anodes, bare or in our exclusive VIBRA-PAK package.

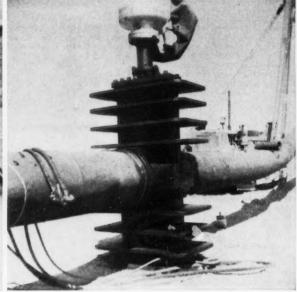
QUALITY AND DEPENDABILITY THROUGH RESEARCH



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# EL PASO NATURAL GAS COMPANY PROTECTS LINE VALVES WITH ROSKOTE COLD-APPLIED MASTIC





Roskote cold-applied mastic was spray-applied to 30" valves by El Paso Natural's personnel at Grants, New Mexico. Risers and support legs were coated with Roskote and wrapped with Royston Glas-Wrap for additional mechanical abrasion protection.

On the El Paso Natural Gas Company line being laid at Fort Stockton, Texas, by Western Pipeline Company, all 20" valves were spray-coated with Roskote cold-applied mastic.

You get superior protection against the most severe field corrosive agents with Roskote cold-applied mastic. Valves, risers, line pipe, tanks and other structures above or below ground are coated with Roskote by spray or brush without heat, flame or toxic and irritating effect on workers. The quick-drying feature of these mastics permits early backfilling. Roskote's time-saving, cost-saving application complements its low first cost to provide you with the most economical means of long-life metal protection.

Roskote is applied cold winter or summer. It retains its plasticity at 0°F, and will not run or sag at 250°F. Its high dielectric strength and resistivity, and its superior resistance to acids and alkalies provides ample protection even under the most rigorous underground or atmospheric corrosive conditions. Specific formulations are available for resistance to high crude oil concentrations and gasoline seepage in surrounding soil.

Royston engineers will give prompt attention to your inquiry.

### ROYSTON LABORATORIES, Inc., P.O. BOX 112-C, PITTSBURGH 38, PA.

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P.O. Box 1084 Atlanta, Georgia P.O. Box 1753 Tulsa, Oklahoma P.O. Box 8188 Houston 4, Texas 1605 Ventura St. Midland, Texas 3114 Midvale Avenue Philadelphia 29, Pa.

Overton Sales Equipment Co. 5981 Fairmount Extension San Diego 20, Calif.



5225 Clover Drive Lisle, Illinois (Chicago District)

# **Equipment Services**

# **NEW PRODUCTS**

### Materials Literature

### Coatings, Organic

X-Tru-Coat, a high density extruded polyethylene coating for protecting pipe irom soil acids, electrolytic action and chemical reactions, is applied to manufacturers' pipe at three plants of Hill Hubbell Company, 3091 Mayfield Road, Cleveland 18, Ohio. Pipe sizes ¾ to 4½-inch OD can be coated at Hammond, Ind., and Lorain and Youngstown, Ohio. Transit privileges are available through Hammond.

Six industrial cold coatings are described in product folders available from the manufacturer, Tar Products Division of Koppers Company, Inc., Koppers Building, Pittsburgh 19, Pa. The six are: (1) Bitumastic 50 for sheet steel, structural piling, distribution piping, marine installations, acid tanks and reactor foundations. (2) Bituplastic 28 for protecting metals against industrial fumes and weathering. It also is used to protect concrete, brick and masonry. (3) Bitumastic Super-Service Black for use in corrosive environments above or below ground, including reinforced concrete pipe, tanks and metal surfaces subjected to sewage gases and fluids. (4) Bitumastic Black Solution for metal and concrete surfaces in corrosive including attention atmospheres. (5) Bitumastic Tank Solution for surfaces in contact with potable water or air, including water treatment equipment, air ducts, service pipelines and piping for humidifying systems. (6) Bitumastic Hi-Heat Gray for hot metal surfaces exposed to corrosive atmospheres in process plants and steel mills, including stacks, furnaces and incinerators, heat exchangers and exhausts.

Two high build urethane coating systems are reported by the Carboline Company, 32 Hanley Industrial Court, St. Louis 17, Mo. One system, called Carboline 131, consists of a 2-mil primer coat, a 4-mil build coat and a 1½-mil finish, This system is formulated for use in mildly corrosive atmospheres over clean steel or almost any painted surface. The other system, Carboline 132, is recommended for resistance to severe fumes and chemical spillage. Application consists of 2-mil prime coat, a 6-mil build coat and a 1½-mil finish.

### Instruments

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Major sulfur compounds in hydrocarbon gases can be measured accurately and quickly with a new gas analysis instrument available from American Systems, Inc., 1625 East 126th St., Hawthorne, Cal. The Model 3013 Olfactron, a portable unit, can be used by nontechnical personnel. It analyses from either a flowing sample stream or an absorbed batch sample by generating by electrolysis metered amounts of bromine or iodine. Hydrogen sulfide and mercaptans are separated from other sulfur compounds by selective filters. Sensi-

tivity is 0.01 grains of hydrogen sulfide per 100 cu ft at 0.5 liter-a-minute flow rate. Ranges are available from 0 to 2 and 0 to 10 grains. Additional information is available from the company on request.

New portable pH meter featuring a plus or minus 500 mv scale and a full range shock resistant combination electrode is manufactured by Sel-Rex Instruments Division. The Meaker Company, Nutley, N. J. Standard are constant reading meter, amplifier-stabilized drift-free indicator needle, reference pointer, easily connected solid ground, fast response tubes and 115-volt line operation. Accurate measurements from 0 to 14 pH at 15 to 70 C are possible, Sel-Rex says. Several combination electrodes, including those for service to 130 C, also are available.

### Valves

Top entry ball valve constructed of either cadium plated carbon steel or stainless steel bar stock are available from Strong, 508 Sandusky Street, Conneaut, Ohio. Threaded inlet and outlet connectors permit positive installation in 36, ½, ¾ and 1-inch lines. Maximum pressure-temperature ratings for the new valves, called Evrtyte, are 150 psi at 635 F for steam lines and 1000 psi for water, oil, liquid chemical and gas handling applications. Chrome plated bronze or stainless steel ball rests between Buna-N or Teflon seals. Flow diameters through ball are 0.500 inch on ¾ and ½-inch sizes, 0.625 inch on ¾-inch size and 0.824 inch on 1-inch size.

Valves designed for use on corrosive gas instrumentation, control and similar processing lines are marketed by Superior Valve & Fittings Company, 1509 West Liberty Avenue, Pittsburgh 26, Pa. Type 5939 features a positive metallic diaphragm seal to insure pressure tight operation from 2500 psi to a vacuum of 0.05 microns at —60 to 400 F. A metering valve, Type 5940, has stem threads isolated from line contents by Teflon packing to protect threads from deterioration upon contact

with corrosive materials in the system. It is designed for operation between 2500 psi pressure and 0.1 micron vacuum at —60 to 400 F. Valves are available in brass, 303 stainless steel and aluminum silicon bronze.

A new globe-type valve introducing a non-rotating stem with a non-rising handwheel and a fixed disc eliminates stem vibration and disc chatter, galling between stem foot and disc and tendency of stem in conventional design to cut spirals through packing, according to manufacturer, Alloy Steel Products Company, Linden, N. J. ASP has incorporated the new design in its 150-lb globe, angle and Y valves in 2-inch sizes and larger. All three valve types are available with renewable discs of Teflon or other suitable materials in 18-8 S, 18-8S Mo, Aloyco 20, Monel, nickel and Hastelloy B and C.

### Wire

High tensile stainless steel spring wire in 0.003 to 0.195-inch diameters is marketed as NS-355 by National-Standard Company, Niles, Mich. Potential applications include springs for jet engines, food and beverage equipment and chemical machinery, manufacturer says. Guaranteed minimum tensile strength of 0.195-inch wire is 290,000 psi. Modulus in torsion at room temperature is 11 to 11½ million psi. Density is 0.282 lb per cu inch. Modulus of elasticity ranges from 29.3 million psi at 80 F to 24.6 million psi at 800 F. Wire is slightly attracted to a magnet when annealed and very readily attracted when spring tempered. Electrical resistivity ranges from 75.73 microhm-cm at 82 F to 109.8 microhm-cm at 1394 F.

Stainless steel wire with electroplated brass finish developed to provide good adhesion of brass to rubber with corrosion resistance of stainless is marketed by National-Standard Company, Niles, Mich. First applications are expected in high pressure hose and timing belts. Electro-plated stainless wire in 0.007 to 0.103-inch diameters is available in all common types of stainless.

# Sates Safe storage for corrosive liquids...

Gates can supply tanks protected by a choice of lining materials best suited to give safe storage for your corrosive liquids.

Low cost tanks . . . fast delivery!

Gates-tank plants at Sioux City, Iowa, and Denver, Colo., specialize only in corrosion protec-

tion. Tanks can be quickly lined upon order at low cost.

Large choice of tank designs. Many popular models of lined tanks are in stock for immediate delivery.



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# corrosion control at lowest cost per day\*

There are several ways of looking at the cost of corrosion control in cooling water systems. But the only one that means anything from a dollars and cents standpoint is... getting good control at the lowest cost per day. Here are some figures that underline this concept. They are the result of a series of trials, each conducted over a 30-day period in the same plant. Test strips were located at the same points under identical conditions.

Inhibitor	mg/dm <sup>2</sup> /day	mils/year	cost/day
*HAGATREAT 168	7.2	1.31	\$32
Product A	39.4	7.2	35-40
Product B	26.9	4.95	35-40
Product C	18.19	2.93	32
Product D	34.0	6.2	25
Product E	6.9	1.3	100

Hagatreat is a recent Hagan development that not only provides optimum corrosion control at a very low cost/day, but also simplifies the treatment of cooling water systems. It is effective in protecting iron, steel and copper against corrosion damage with no tendency towards pitting. It stops sludge and scale, and it is easy to handle and feed.

If you would like more information on effective, low cost Hagatreat, write or phone:

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HAGAN CENTER, PITTSBURGH 30, PENNSYLVANIA

# HAGAN DIVISIONS: CALGON CO. HALL LABORATORIES BRUNER CORP.

# MEN in the NEWS

NACE Member Robert E. Simpson is president of the newly formed Mineral Fiber Mfg. Corp., 3271 West Alabama Houston, Texas. Initially the company will manufacture glass fiber felt for pipelines. W. P. Bonin and J. P. Bristow have been named vice presidents and George Hillyer and James A. McBride directors

Julian Pode, deputy chairman and managing director of The Steel Company of Wales, Ltd., has been elected a vice president of The Iron and Steel Institute, 4 Grosvenor Gardens, London S.W. 1, Eng. H. W. A. Waring, general managing director and deputy chairman of GKN Steel Company, Ltd., has been elected honorary treasurer of the institute.

Jerry G. Holecek has joined Anchor Alloys, Inc., 968 Meeker Avenue, Brooklyn 22, N. Y., as a research chemist in Anchor's new plastics division.

NACE Member Bernard Husock, chief engineer of Cathodic Protection Division, Harco Corporation, 4600 East 71st Street, Cleveland, Ohio, has been awarded first prize for his technical paper, Effects of Electrical Grounding Systems on Corrosion, by the American Institute of Electrical Engineering.

W. D. Manly has been appointed director of the gas cooled reactor program at Oak Ridge National Laboratory, Oak Ridge, Tenn.

Crucible Steel Company of America, Pittsburgh 22, Pa., has appointed William H. McCormick company metallurgical engineer and William R. Mogg assistant director of metallurgy—technical services.

Robert C. Beckwith has been appointed manager, manufacturing engineering, for the Henry Pratt Company, 319 West Van Buren Street, Chicago 7, Ill.

Richard H. Braunlich has been appointed manager of research and development for Fibers Division of American Viscose Corporation, 1617 Pennsylvania Boulevard, Philadelphia 3, Pa.

Charles A. Suter has been elected president of Geigy Chemical Corporation, Ardsley, N. Y.

Merle J. Davis has been named sales manager of Anchor Alloys, Inc., 968 Meeker Ave., Brooklyn 22, N. Y.

NACE Member V. B. Pike has retired from Bell Telephone Laboratories, Inc., 463 West, New York 14, N. Y.

NACE Member E. R. Perkins has retired from the New England Telephone & Telegraph Company, 185 Franklin, Boston 7, Mass.

Curry E. Ford has been named director of development and William C. McCosh director of marketing for National Carbon Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y.

(Continued on Page 59)

### MEN in the NEWS

(Continued From Page 58)
Myron Youdin has been named vice president, engineering, of Lionel Electronic Laboratories, 1226 Flushing Aveue, Brooklyn, N. Y. Lionel Electronic, ormerly Anton Electronic Laboratories, is a subsidiary of the Lionel Corporation. Luigi M. Ferrari has pined Lionel Electronic as vice president, manufacturing and administration; Herbert Kalisman has been made gen-Herbert Kalisman has been made genral sales manager.

Amel R. Meyer has been appointed ection head of the Research and Declopment Department, American Oil lompany, Whiting, Ind.

Charles E. Miller has been appointed Houston District Manager by The Carbenter Steel Company, 101 West Bern St., Reading, Pa. He will direct sales in Texas, Southern Arkansas, New Mexico, Colorado, Wyoming and Montana.

NACE Member Carl F. Prutton, director-consultant of Food Machinery and Chemical Corporation, Coronado Pines, Oklawaha, Fla., will present the keynote address at the 39th annual meeting of the Federation of Societies for Paint Technology to be held at the Shoreham Hotel, Washington, D. C., November 2-4, 1961.

W. C. Rosenbaum has been named manager of operations of the Carboline Company, 32 Hanley Industrial Court, St. Louis 17, Mo.

NACE Member Marion F. Hutchison has been appointed district sales manager for Fibercast Company in San Francisco, Cal. His territory will be Northern California, Washington and

Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y., has ap-pointed Richard S. Abrams manager of development of its Olefins Company and James C. Malone general manager of the Silicones Division.

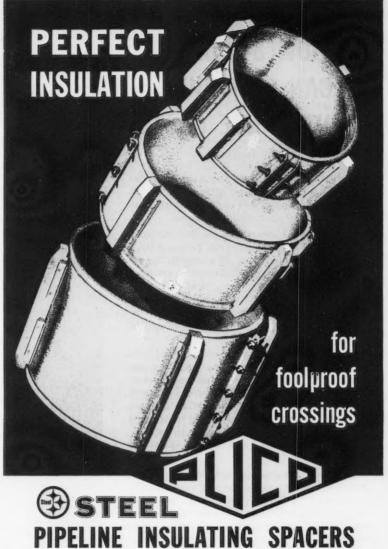
NACE Member Herman S. Preiser, president and technical director of Chemionics Engineering Laboratories, Inc., 1 Bala Avenue, Bala-Cynwyd, Pa., has announced the affiliation of four other NACE members as associate consultants for Chemionics. These members are Andre J. De Bethune' Marshall E. Parker, Walter H. Bruckner and Boris H. Tytell.

Quentin Nelson & Company, 102 Palmer Street, Houston 3, Texas, has been appointed sales agent for Union Carbide Plastics Company to service the protective and decorative paint industry in Texas.

Phillip J. Liston has been named assistant sales manager in charge of special projects for Fibercast Company, Sand Springs, Okla.

B. H. Pickard has been named director of sales of Plastic Applicators, Inc., 7020 Katy Road, Houston, Texas.

Ernest R. Ramirez has been appointed senior research supervisor of Special Metals, Inc., New Hartford, N. Y.



You cannot afford not to buy the strongest, safest insulating spacers ever produced!

RUGGED HEAVY DUTY STEEL BODY, hot dip galvanized and enameled the distinctive PLICO Yellow, Defies corrosion and abuse, Complete lines in 6, 8 or 12-in, body widths.

VIRGIN POLYETHYLENE LINER-no fillers-no "regenerated" scrap - beefed up in entire edge area to eliminate cuts or short-outs even if a spacer should cock as it is slid into the casing. Assures positive, permanent insulation.



FLINT-HARD MICARTA SKIDS shrug off abrasion and heaviest loads. Outstanding dielectric and mechanical qualities give unusual margin of safety.

Everything about PLICO STEEL Spacers-including hot dip galvanized fastenings-is top quality . . . yet they cost no more than so-called "economy" spacers. Why compromise? Why send a boy to do a man's job? CALL YOUR NEAREST PLICO DISTRIBUTOR OR WRITE US FOR FULL DATA AND PRICES.



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# "LET ME SHOW YOU HOW DU PONT CAN CUT YOUR MAINTENANCE COSTS!"

Meet Frank Smith, shown here on the job. A member of Du Pont's nationwide team of Technical Service experts, Frank's job is to see that you derive maximum returns from every paint dollar you spend.

"A true low-cost approach to maintenance painting," explains Frank, "hinges on two factors of equal importance: paint quality and job suitability. You get both with Du Pont. Take the problem of severe corrosion brought on by acid spillage, fumes and vapors. In-use evaluations at paper mills, refineries, bleacheries and chemical plants prove there's no finer finish for this purpose than our new IMLAR(TM) Vinylmastic Coatings and Vinyl Enamels.

"But that's just one example. Whatever your problems, you can be sure the finishes used meet your needs exactly. It's all a part of our planned technical assistance—a valuable bonus you get when you specify Du Pont's system of maintenance painting. It means going right into your plant and working out a sound program of paint maintenance geared for efficient, long-range protection at lowest cost per square foot per year!"

Over 13 years' experience with corrosion problems makes Frank Smith typical of the able, expert help you can expect from Du Pont. Why not call your local Du Pont district sales office the next time you have a corrosion problem? For facts on the finishes mentioned here, just clip and mail the coupon below.

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### E. I. du Pont de Nemours & Co. (Inc.)

Finishes Division, Department C-110 Wilmington 98, Delaware

- Please send me, without obligation, technical bulletin on IMLAR.
- Please have Du Pont Technical Representative schedule

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### MAINTENANCE PAINTS



BETTER THINGS FOR BETTER LIVING ... THROUGH CHEMISTRY



Northeast Conference October 30-November 2 Statler Hilton Hotel New York, New York

Monday, October 30 2-5 pm T-8A, Penn Top North T-2K-3, Town Room T-5C-3, Empire Suite

Tuesday, October 31 9-12 am T-8, Headquarters Room T-6F, Town Room 2-5 pm T-8, Headquarters Room T-3G-1, Penn Top South T-4G, Town Room

North Central Region October 9-11 Chase Park Plaza Hotel St. Louis, Missouri

Monday, October 9 2-4:30 pm T-5D, Georgian Room

Tuesday, October 10 9-11:30 am T-6D-5, Georgian Room 2-4:30 pm T-5C-2 T-5C-2, Stockholm Room T-6D-6, Georgian Room

South Central Region October 23-26 Shamrock Hilton Hotel Houston, Texas

Monday, October 23 9-12 am T-1G, Continental T-2J-5, Normandy A T-6D-10, Nile 1:30-4:30 pm T-1D, Continental T-2J, Normandy A T-5A-1, Nile T-6D, Grecian

Tuesday, October 24 9-12 am T-1C, Continental T-5A-2, Nile T-6A, Camellia T-6B-19, Normandy B 1:30-4:30 pm T-5A-3, Ni Nile T-6B-20, Normandy A T-6B-9, Normandy B

Wednesday, October 25 9-12 am Continental T-1F 1:30-4:30 pm T-1E, Continental T-2, Nile

Thursday, October 26 9-12 am T-1H, Continental T-5C-1, Nile T-6G, Grecian 1:30-4:30 pm T-6B, Grecian

### Corrosion Inhibitors to Be Topic of T-5C-2 Meeting

T-5C-2, Corrosion by Cooling Waters, will hold its fall meeting at the North Central Region Conference being held October 9-11 at the Chase Park Plaza Hotel, St. Louis, Mo.

The committee's meeting, to be held at 2 pm, October 10, in the Chase's Stockholm Room, will cover evaluation of cooling water corrosion inhibitors used in process and pilot plant applications. Several speakers and a panel discussion are scheduled.

### T-1C to Hear Reports on **Electronic Inspections**

T-1C, Detection of Corrosion in Oil Field Equipment, has an interesting program for its October 24 meeting, which is being held in conjunction with the South Central Region Conference at the Shamrock Hilton Hotel, Houston.

The committee has commitments from Tuboscope, Welex, International Inspec-tion (Triple Eye) and Plastic Applica-tors (Inspection Division) for 15-minute formal presentations on their work in electronic and ultrasonic downhole or rack inspection of oil field tubular goods.

### Light and Color to Be Discussed at T-6D Meeting

T-6D, Industrial Maintenance Painting, at its October 23 meeting at the Shamrock Hilton's Grecian Room will hear L. G. Schmieg of E. I. du Pont de Nemours & Company discuss light and color.

The discussion, to cover physical aspects of light and color, the psychological effect of color and effects of illumical effect of color and effects of littlem-nation on color, will be followed by a Du Pont film entitled "A Case for Color" illustrating practical benefits of the principle of color conditioning.

# On Metallizing Report

Task Group T-6B-20 on Metallizing will meet Tuesday, October 24, at the Shamrock Hilton, Houston, to begin work on a committe treport. Tentatively, the group will meet in Normandy Room "A" at 1:30 pm. Anyone interested in "A" at 1:30 pm. Anyone interested in joining this committee should contact chairman Fred W. Gartner, Jr., F. W. Gartner Company, Box 1303, Houston, Texas. Vice Chairman is S. John Oechsle, Jr., Metalweld, Inc., 2617 Hunting Park Avenue, Philadelphia, Pa.

# **Lapel Pins**



Approximately 7/16 inches high, gold, inlaid with bright red enamel background to "NACE" and deep blue enamel background to words "CORROSION CONTROL." Ruby center.

For Association Members Only

On sales to Texas addresses, add 2% tax.

Address Orders to T. J. Hull, Executive Secretary

### NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg., Houston 2, Texas

### Membership in NACE Technical Unit Committees

A question frequently asked by guests attending meetings of Technical Unit Committees is "How may I become a member of this committee?" This question is answered in the following procedure quoted from the Technical Committee Operation Manual:

1. Any member of NACE (irrespective of place or country of residence) may become a member of a Technical Unit Committee upon fulfillment of the following require-

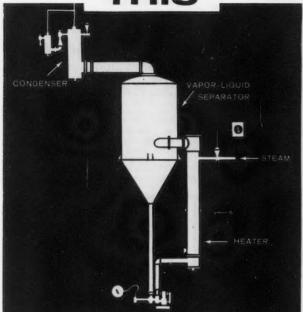
2. He should apply in writing to the Chairman of the Unit in which he desires membership, stating his interest and willingness to participate in the activities of the

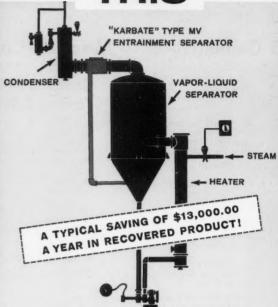
Unit and giving his experience in the sub-

3. Approval by the Chairman of the Unit Committee of the application or by majority vote of committee members by letter ballot is necessary for appointment of an applicant to membership in a Unit Committee.

4. The Chairman of the Unit Committee will notify each applicant of his acceptance or rejection.

# THE DIFFERENCE BETWEEN THIS and THIS





# is a corrosion-resistant "KARBATE" IMPERVIOUS GRAPHITE TYPE MV ENTRAINMENT SEPARATOR!

The difference between no separator and an efficient "Karbate" entrainment separator on an evaporator is increased profit and reduced condensate contamination. A very small product loss in the overhead vapors from an evaporator—even when handling low cost chemicals—adds up to a substantial amount in a year.

For example, a one percent loss of  $P_2O_5$ , valued at four cents a pound, is not considered unusual for a phosphoric acid evaporator. An evaporator operating 7,000 hours per year and handling three tons per hour of  $P_2O_5$  will lose roughly \$16,800 per year. A large part of this loss can be recovered with a "Karbate" impervious graphite Type MV entrainment separator, paying-out the cost of this equipment — \$4,000 including a lead lined transition section or \$2,500 with a rubber lined transition section — in a very short period.

In addition to low cost, "Karbate" impervious graphite Type MV entrainment separators offer these features: complete corrosion resistance... high operating efficiency...low pressure drop... simple construction—easily cleaned. For details, write for Catalog Section S-6900.



"National," "Karbate" and "Union Carbide" are registered trade-marks for products of

### NATIONAL CARBON COMPANY

Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N.Y.

IN CANADA: Union Carbide Canada Limited, Toronto

UNION CARBIDE



# NACE NEWS

# **Technical Program Set for Houston Meeting**

# Conference and Exhibition to Be Held at Shamrock

The South Central Region Conference technical program has now been set. Centering on the oil industry, the conference will be held October 23-26 at the Shamrock Hilton Hotel, Houston, Texas. An exhibition of corrosion control products is being held in conjunction with the precise. with the meeting.

Nine symposia make up the program.
They are: Aluminum, Oil and Gas Production, Utilities, Industrial Maintenance Painting, Pipe Lines, Chemical and Petrochemical Industry, Marine and Offshore, Cathodic Protection and Galvanic Anodes.

Conference Chairman is C. L. of United Gas Corporation, Houston. Vice Chairman is Ben Russell of Russell & Sharpe, Inc., Houston. Technical Program Chairman is M. A. Riordan of Engineering Company, Houston. Technical Program Co-Chairman is Ma-rion Frank of Tennessee Gas Pipeline

Company, Houston.
Technical committee to meet during the conference are listed in the Technical committee to meet during the conference are listed in the Technical Committee to the Technical Committee of the Te cal Committee Activities section of this

issue. Registration starts at 2 pm, October 23, in the Shamrock lobby. See September Corrosion, Page 60, for complete registration information.

The technical program is as follows:

### October 24 Tuesday Morning Aluminum Symposium

Chairman: Maurice A. Riordan of Rio Co-Chairman: Walfree A. Riordan of Roberts Co-Chairman: W. H. Edwards of Superior Oil Company, Houston, Texas.

Atmospheric Weathering and Marine Service Characteristics of Aluminum

Service Characteristics of Aluminum Alloys by T. J. Summerson of Kaiser Aluminum and Chemical Corporation,

Spokane, Wash.

Aluminum Alloys for Chemical and Petrochemical Service by R. S. Dalrymple and R. W. Fluornoy of Reynolds Metals Company, Richmond, Va.

Aluminum Pipe Lines and Their Protection by Ellis D. Verink, Jr., and M. E. Carlisle, Jr., of Aluminum Company of America, Pittsburgh, Pa.

Round Table Discussion. Moderator: W. E. Edwards, Panel Members: T. J. Summerson, R. S. Dalrymple and Ellis Verink, Jr.

#### Tuesday Afternoon Oil and Gas Production Symposium

Chairman: J. A. Caldwell of Humble Oil & Refining Company, Houston, Texas. Co-Chairman: E. J. Simmons of Sun Oil Company, Dallas, Texas. Corrosion Characteristics of "Gyp Mud" Drilling Fluids by C. O. Bundrant of Champion Chemicals, Inc., Houston,

Texas.

Cathodic Protection of Surfaces of Well Casing by F. E. Blount and P. W. Bolmer of Socony Mobil Oil Com-pany, Inc., Dallas, Texas.

Corrosion Control in the East Texas Field by B. W. Cato of Tidewater Oil Company, Kilgore, Texas.

Simplified Caliper Survey Presenta-tion Methods by P. E. Pilkington of Continental Oil Company, Lake Charles,

### Utilities Symposium

Chairman: D. E. Simmons of Houston Lighting & Power Company, Houston, Texas. Co-Chairman: K. D. Wahlquist of Southern Union Gas Company, Dal-Texas.

Intake Screen and Condenser Water ox Protection With Lead-Silver nodes by Will French of Houston Anodes by Will French of Houston Lighting & Power Company, Houston,

Corrosion and Its Relation to Tele-phone Protection by Charles M. Wood-man of Southwestern Bell Telephone

Company, Houston, Texas.

Details of a Company Corrosion Control Training and Organization Program by Joe P. Shultz of Lone Star Gas

Company, Dallas, Texas.
Tainter Gate Corrosion Protection by
Glyn Beesley of Dallas Power and Light Company, Dallas, Texas.

#### October 25 Wednesday Morning Industrial Maintenance Painting

#### Symposium

Chairman: F. Parker Helms of Union Carbide Chemicals Company, Texas City, Texas. Co-Chairman: Don D. Cone of Texas Butadiene and Chemical

Cone of Texas Butadiene and Company, Channelview, Texas.

A Comparison of Contract Painting and Plant Painting—Interim Report of Monsanto

T-6D-8 by Norman Erd of Monsanto Chemical Company, Texas City, Texas. Designing for Corrosion Control—Interim Report of T-6D-9 by W. A. Wood, Jr., of Carboline Company,

Houston, Texas.
T-6D-7 Coating Clinic—Panel Discussion. Moderator: Joe Rench of Napko Corporation, Houston, Texas.

### Pipe Line Symposium

Chairman: A. T. Surber of Trunkline Gas Company, Houston, Texas. Co-Chairman: Paul D. Palmer of Columbia Gulf Transmission Company, Nashville,

New Resins, New Techniques and New Thoughts on Corrosion Resistant

New Thoughts on Corrosion Resistant
Coatings by Donald F. Koenecke of
Enjay Laboratories, Linden, N. J.
Reducing Friction Losses in Pipe
Lines—Panel Report: Laboratory
Studies of Internal Coatings by W. H.
Jamison of Tennessee Gas Transmission
Company, Houston, Texas. Field Experience With Internal Coatings by
C. H. Klohn of Tennessee Gas Trans-H. Klohn of Tennessee Gas mission Company, Houston, Texas. In-ternal Sandblasting of Pipe Lines in Place by A. W. McAnneny of Trunk-line Gas Company, Houston, Texas.

Design and Application of Aluminum Pipe Lines by L. E. Pennington, D. V. Wilcox and R. S. Dalrymple of Rey-nolds Metals Company, Richmond, Va. Required Characteristics and Testing

Required Characteristics and Testing of Underground Coatings—Panel Discussion and Open Forum. Moderator: Russell Brannon of Humble Pipe Line Company, Houston, Texas. Panel Members: Loly B. Nelson of Shell Pipe Line Corporation, Houston, Texas; Donald F. Koenecke of Enjay Laboratories, Linden, N. J.; R. J. Emerson of El Paso Natural Gas Company, El Paso, Texas and Jack P. Barrett of Pan American Petroleum Corporation, Tulsa, Okla.

### Wednesday Afternoon

#### Chemical and Petrochemical Industry Symposium

Chairman: W. G. Ashbaugh of Union Carbide Chemical Company, Texas City, Texas. Co-Chairman: E. V. Kunkel of celanese Chemical Corporation, Bishop,

Ductile Iron—The Metal of the Future by Jack H. Marsh of Stockham Valve Company, Birmingham, Ala.

Vaive Company, Birmingham, Ala.

Design and Application of High Performance Metals in CPI Equipment by
L. C. Rodgers of The Pfaudler Company, Rochester, N. Y.
17-4 PH, A High Strength Precipitation Hardening Stainless Steel for Chemical Industry by John Halbig of Armco Steel Corporation, Middletown, Ohio.

Ultrasonic Inspection of Lead Bonded Equipment by A. W. Gilbert of Union Carbide Chemical Company, Texas City. Corrosion Problems in Chemical In-

dustry—Panel Discussion and Open Forum. Moderator: W. G. Ashbaugh of Union Carbide Chemical Company, Texas, City, Texas.

### Marine and Offshore Symposium

Chairman: D. B. Stauffer of Humble Oil & Refining Company, Houston, Texas. Co-Chairman: Otto Grosz of California Company, New Orleans, La. Influence of Magnesium on Corro-sion Resistance of Galvanized Coatings

by L. M. Vaught, J. A. Heath and C. F. Schrieber of Dow Chemical Company, Freeport, Texas. In Line Generator for Cathodic Protection of Offshore Facilities—Preliminary Report by S. J. Bellassai of Transcontinental Gas Pipe Line Corporation, Houston, Texas.

Compatibility of Zinc Anodes to Hy-

Compatibility of Zinc Anodes to Hydrocarbon Environment by C. W. Ambler of American Zinc, Lead and Smelting Company, East St. Louis, Ill. Corrosion Control of Offshore Facilities—Panel Discussion and Open Forum: Protective Coatings by W. F. Oxford, Jr., of Sun Oil Company, Beaumont, Texas. Cathodic Protection by R. M. Robinson of Continental Oil Company. Robinson of Continental Oil Company, Houston, Texas. Structural Design and Construction Aspects of Corrosion Control by C. K. Reese, Jr., of Humble Oil & Refining Company, Houston.

(Continued on Page 64)

# South Central Region



PAST CHAIRMEN of Shreveport Section were presented plaques for their leadership and service at the section's September 5 meeting. Above, Section Chairman Grady Howell presents plaques to (left to right) 1956 Chairman G. V. Jones, 1951 Chairman Tom Holcombe and 1952 Chairman M. J. Olive.

### Shreveport Section Honors Past Chairmen

In appreciation of their leadership and service, the Shreveport Section pre-sented plaques to its past chairmen September 5.

In photograph above, Section Chairman Grady Howell (left) of Tube-Kote, Inc., presents plaques to (left to right) 1956 Chairman G. V. Jones of Arkansas Louisiana Gas Company, 1951 Chairman Tom Holcombe of Holcombe Company and 1952 Chairman M. J. Olive of Corrosion Control Associates.

Also honored were:
W. A. Broome of Arkansas Louisiana
Gas Company, 1947 Chairman.
T. B. McDonald of United Gas, 1948

Chairman.

Belson of D. E. Stearns Maurice Company, 1949 Chairman.

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41/2 oz. Sea Rite Salt crystals in one gallon tap water produces laboratory sea water quickly, inexpensively. Provides uniform, constant results based on 77 composite analysis. Immediate delivery - any quantity. Technical literature on request. Write, wire, phone now!

LAKE PRODUCTS CO., Inc. LOUIS 25, MISSOURI H. V. Beezley of United Gas, 1950

Chairman. W. F. Levert of United Gas, 1953-54 Chairman.

R. C. Jordan of Magnolia Pipe Line, 1955 Chairman. E. H. Sullivan of United Gas. 1957

Chairman. L. B. Irish of Irish Engineering, 1958

John Wise of Arkansas Louisiana Gas Company, 1959 Chairman. R. P. Naremore of Sunray Midconti-nent Oil Company, 1960 Chairman.

### **Tulsa Section Schedules** Short Course Feb. 21-23

The 12th Annual Corrosion Short Course for Pipeliners will be held by the Tulsa Section February 21-23, 1962, at the Mayo Hotel in Tulsa, Oklahoma.

To stress practical control of pipeline corrosion, the program is specifically designed for foreman, superintendents, design engineers, field engineers and in-

Subjects to be covered include pineline coatings, corrosion surveys, cathodic protection, internal pipeline corrosion

protection and instrumentation.
Chairman is E. W. Lawlor. James A. Rush is publicity chairman.

Central Oklahoma Section heard William E. Billings of Halliburton Company speak September 11 on Acid Volume and Inhibitor Quantity—Their Effect on Corrosion of Steel in Hydroslatesia. chloric Acid.

For October 2, the section scheduled a movie of Cathodic Protection Service on cathodic protection. This meeting will be held at Hart's Cafeteria, Oklahoma City, at 6:30 pm. Meetings are now held the first Monday of each month.

### **Houston Meeting**

(Continued From Page 63)

October 26 Thursday Morning

Cathodic Protection Symposium

Chairman: Marion E. Frank of Ten-Charman: Marion E. Frank of Ten-nessee Gas Pipe Line Company of Houston, Texas. Co-Chairman: R. J. Emerson of El Paso Natural Gas Com-pany, El Paso, Texas.

Zinc Anodes for Protection of Crude Oil Cargo Tanks by B. C. Lattin of Ebasco Services, Inc., New York, N. Y., and W. Quimby of Texaco-Panama, Inc., Beacon, N. Y.

Use of Parallel Ground Beds for Cathodic Protection of Bare Pipe Lines by B. M. Dearing of Texas Eastern Transmission Corporation, Shreveport,

Practical Interference Current Testing on Underground Metallic Structures by R. L. Seifert of Tennessee Gas Pipe Line Company, Buffalo, N. Y.

The Remote Electrode in Cathodic Protection of Well Casings by M. A. Riordan of Rio Engineering Company, Houston, Texas.

Thursday Afternoon Galvanic Anodes Symposium

Chairman: Walter Noser of Humble Pipe Line Company, Houston, Texas. Co-Chairman: Stanley Kleinheksel of Magnolia Pipe Line Company, Dallas, Texas.

Magnesium as a Galvanic Anode by Marshall Parker, Houston, Texas.

Zinc Galvanic Anodes-Practical Electrochemical Properties and Applications by T. J. Lennox, Jr., of American Smelting and Refining Company, South Plainfield, N. J.

Latest Development With Aluminum Alloy Anodes by R. L. Horst of Alu-minum Company of America, New Kensington, Pa.

Field Reports and Open Forum. Moderator: Walter P. Noser of Humble Pipe Line Company, Houston, Texas.

### Houston Section Arranges Program Through January

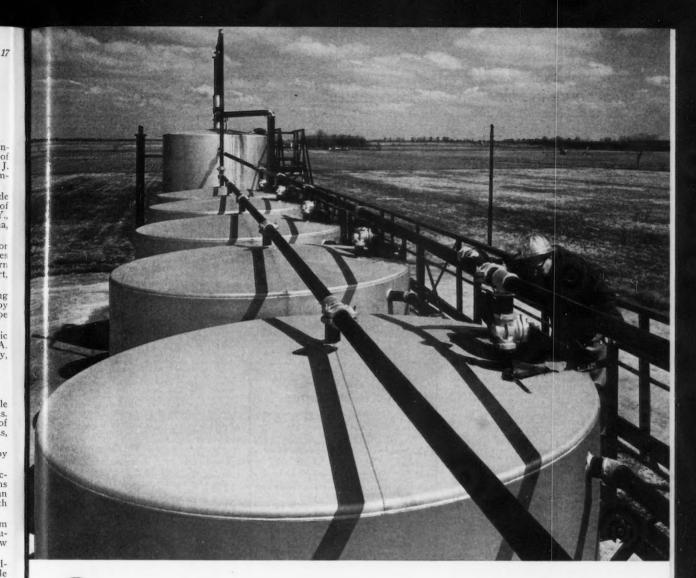
Houston Section's program schedule through January, 1962, is as follows:

October 23-26-Regional Conference. November 14-Students' Night. Tentatively, Moody Adams of Matcote, Houston, Texas, will speak on hydraulic spray application of fiberglass reinforced epoxy and polyester resins.

December 12—Ladies' Night. J. D. Lindsay, head of the Chemical Engineering Department, Texas A. & M., College Station, will discuss the development of the chemical industry in Texas as well as educational trends in engineering schools.

January 9—F. A. Prange of Phillips Petroleum Company, Bartlesville, Okla., will speak on corrosion problems in production equipment.

Teche Section scheduled a narrated slide show of the 17th Annual NACE Conference and 1961 Corrosion Show held in Buffalo, N. Y., March 13-17, for its September 6 meeting at the Petroleum Club. Fall meetings will be held on the first Wednesday of each month.





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# Procedure in Selection of Persons to Receive Whitney and Speller Awards

Procedure in the Selection of Persons to Re-ceive the Willis Rodney Whitney and Frank Newman Speller Awards as Approved by the Board of Directors, December 4, 1953, and Revised March 6, 1955, December 7, 1957, and November 18, 1960.

The Board of Directors of the National Association of Corrosion Engineers in a regular meeting on January 17, 1947, authorized the presentation annually of two awards by the

meeting on January 17, 1974, authorized presentation annually of two awards by the Association:

The Willis Rodney Whitney Award is given in recognition of public contributions to the science of corrosion. A contribution to science is defined as the development of a more satisfactory theory which contributes to a more fundamental understanding of corrosion phenomena.

The Frank Newman Speller Award is given in recognition of public contributions to corrosion engineering. A contribution to engineering is defined as the development or improvement of a method, apparatus or material by which the control of corrosion is facilitated or made less costly.

in recognition of pulsic contribution to engineering is defined as the development or improvement of a method, apparatus or material by which the control of corrosion is facilitated or made less costly.

Not later than January 1st of each year, the President in consultation with the immediate past President shall appoint an awards committee. This committee shall consist of at least six members with the President serving as Chairman. He shall continue to serve as Chairman of the committee for the calendar year and shall present the award to the recipients selected by his committee. In the event the President upon becoming past President should be unable to serve, the President (for the year the award is to be made) shall appoint's Chairman. The other members of the Association. Members shall be appointed for a three-year term with two members being replaced each year. Any member who is lost through resignation or for any other reason, shall be replaced by appointment by the President of the Association.

The Chairman of the Awards Committee shall arrange to keep reasonably detailed records of the activities and discussions of the Committee. These records shall be made available to succeeding Awards Committees.

The Awards Committees shall meet at the Annual Conference is not held or is held later than June 1st, the Chairman shall conduct the committee business by correspondence.

The list of candidates to be considered for the Awards shall include:

A. The names of those proposed by the Chairmen of the Regional Divisions in accordance with the wishes of the members of the Division. Nominations may be made by local sections or may be proposed directly to the Chairman of a Region by individual members. In any case, nominations should be accompanied by an appropriate statement of the basis of the proposal. This statement shall be reproduced and submitted to all members of the Awards Committee. The Committee should have such statement for all noninces to be considered.

Prior to February 1st of each year the Regiona

Awarus Committee member.

At the discretion of the Committee members the resultant list of candidates may be reduced to a workable number by elimination of those known to lack the necessary qualifactions.

As a basis for further consideration by the Committee, the headquarters staff of the Association shall provide the Committee, through its Chairman, with a record of the contributions of each final candidate in the form of a list of his published papers and other works. Such records available in the headquarters office may be supplemented by additional information on the candidates' qualifications which may be secured

by any member of the Committee from other sources, such as friends of the candidates, and especially from the proposers of the candidates who should be asked to provide their reasons for suggesting them and a summary of their accomplishments. Ordinarily, the candidates should not be made aware that they are being considered for awards by seeking such information from them directly.

The required activity of the headquarters staff should be facilitated by appropriate use of the literature abstract filing system.

The list of candidates about whom the headquarters staff is to provide the information described should be sent by the Chairman of the Committee to the Executive Secretary of the Association and to each member of the Committee not later than May 1st.

The information to be provided by the headquarters staff should be sent by the Executive Secretary to the Chairman and each member of the Committee not later than July 1st.

Information secured by any member of the Committee concerning any candidate or candidates should be sent to the Executive Secretary not later than June 15th so that it can be circulated amongst all the members of the Committee not later than July 1st.

Not later than August 1st, each member of the Committee than July 1st.

Not later than August 1st, each member of the Committee his first and second choice nominations for each first and second choice nominations for each member of the Committee his first and second choice nominations for each

Recommendations of the Committee accompanied y a statement from the Awards Committee as why they think each nominee should receive the award shall be reported by the Chairman of the Committee to the Board of Directors through Executive Secretary not later than November

In the event that the Committee should be unable to reach a decision on candidates for either or both awards, the Committee shall provide the Board with a list of all those proposed for consideration and the number of votes received by each on the last ballot of the members of the committee.

for consideration and the number of votes received by each on the last ballot of the members of the committee.

The Board of Directors shall then determine,
either in a regular meeting, or by letter ballot,
returnable not later than December 1st in each
year, whether the recommendations of the
Awards Committee are to be accepted and the
awards made as proposed. If the Board of
Directors do not approve the granting of an
award or awards, as proposed by the Awards
Committee, then such award, or awards, will not
be made for the year in question. In the event
that the Awards Committee has been unable to
reach a decision on candidates for one or both
awards, the Board of Directors shall determine
by majority vote whether an award (or awards)
shall be made and to whom it (or they) shall
be granted.

After the Board of Directors have chosen the
recipients of the awards, the President of the
Association shall notify the recipients not later
than December 15th, and shall invite each of
them to be present at the annual meeting or
other occasion when the awards are to be presented. The Chairman of the Committee shall
arrange to have appropriate certificates inscribed
for presentation to the recipients of the awards
and on occasion of any public presentation of
the awards he shall present the recipients to the
President or whoever may be serving in his
stead as Chairman of the Meeting to receive the
awards at his hands.

The actions of the Awards Committee shall be
confidential and confined to consideration only
as outlined in the procedure until such time as
the President receives acceptance or rejection
from the awardes following his notification to
them. After receiving acceptance of an award or
awarde, the President shall so notify the Executive Secretary who may publicize the information prior to the actual presentation of the
award or awards.

### Notes for Guidance Of Awards Committee

The Committee shall not recommend the same individual for both awards in in any one year.

- the same individual for both awards in in any one year.

  B. Previous recipient of an award is not eligible to receive the same award again.

  C. The recipient of one award is not barred from receiving the other award for some other year.

  D. In considering the qualifications of those nominated for awards, the nominee's total contributions should be taken into account and recent activities should not take precedence over the recognized results of earlier work. Other things being equal, awards should be made to the candidates who have been contributing consistently for the longest period.
- Candidates need not be residents of North America.
- Candidates need not be members of the National Association of Corrosion Engi-
- G. Awards shall be limited to living per-
- sons,

  H. Recipients of the Willis Rodney Whitney and the Frank Newman Speller Awards and the recipient or recipients of the Junior Award should be guests at the annual NACE banquet.

  I. The President and Vice President of the Association and the Chairman of the Awards Committee should not be considered as candidates for awards.

award and shall provide with his nominations his appraisal of the qualifications of those he is nominating and his reasons for preferring them. If a member of the Committee feels that no award should be given, he should so state by August 1st. Failure to nominate either a first or second choice for either award will not relieve a committee member of the duty of voting on the nominations made by others, or of voting that no award be made if those nominated are not considered satisfactory.

Between August 1st and September 1st, the Chairman shall arrange for a letter ballot election by the Committee of those to be nominated for the awards. If no decision can be made by the first ballot, then a second ballot shall be taken on those who have received the most and and second most votes on the first ballot. In the event of a tie for first place on the first ballot, only those names shall be considered in a second ballot. Similarly, in the event of a tie for second ballot. Similarly, in the event of a tie for second ballot. In the event a person is nominated for both awards, his vote for one award shall not be considered in determining his standing in the vote for the other award.

If the Committee should decide that none of those nominated are worthy of the awards, or

If the Committee should decide that none of those nominated are worthy of the awards, or if no nominations are received, the Committee may recommend to the Directors that one or both awards be withheld for reasons to be stated in their report to the Directors.



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Remittance must accompany all orders for literature the aggregate cost of which is less than \$5. Orders of value greater than \$5 will be invoiced if requested, Send orders to National Association of Corrosion Engineers, 1061 M & M Bidg., Houston, Texas. Add 75c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

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corrosion resistant construction material for process equipment

Where corrosive fluids take too great a toll—in tanks, ducts, fume hoods and similar equipment—you and your fabricator should take a long look at glass reinforced ATLAC 382. It offers you seven distinct advantages for process equipment:

Corrosion resistance ATLAC 382 is vastly superior to ferrous metals in corrosion resistance. and generally superior to most nonferrous metals and alloys, as well as general purpose polyester and epoxy resins. It resists attack by many aqueous solutions of acids, salts, bleaches and alkalis, at temperatures up to 250° F. Typical service histories: a tank of ATLAC 382 still in mint condition after 2 years' alternately stor-ing 14% sodium hypochlorite and caustic soda...no attack whatsoever on an ATLAC 382 elbow and damper used to exhaust sulfuric acid pickling fumes . . . zero down-time for a nitric acid scrubber of ATLAC 382, even after 6 years of constant use.

Pligh strength Pound for pound, reinforced ATLAC 382 is stronger than steel. You get the same total strength with less total weight. Examples: 30,000-gallon tanks of ATLAC 382 are completely self-supporting... and even the largest hoods need no corrosion-prone metal bracing.

3 Light weight Equipment of ATLAC 382 is generally lighter than wood, Transite, or metal equipment. In one case, a 1,000-gallon tank of 1/4" ATLAC 382 weighed 300 pounds, compared with

4.3 times that weight for alloy steel.

Economy ATLAC 382 equipment generally costs one-half to one-third less than rubber-lined or tiled equipment, and is normally equal to 304 and lower in price than

equal to 304 and lower in price than 316 stainless steel. It is almost always a better buy than the more exotic metals if temperatures and pressures are not too high.

5 Design flexibility There are very few practical limits in size and shape for equipment of ATLAC 382. What's more, equipment can sometimes be redesigned to take advantage of ATLAC 382's unique structural characteristics—resulting in extra simplification, practicality and cost reduction.

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# Southeast

# Twenty-One Papers Scheduled at Miami Meeting Nov. 27-Dec. 1

# **NACE** President to Open Conference

Twenty-one papers and a soil box demonstration will be presented at the 1961 Southeast Region Conference in Miami November 27-December 1 at the Key Biscayne Hotel.

The technical program is as follows:

### Monday, November 27

9-12 am Registration 1:30 pm Welcome and Introduction of

1:30 pm Welcome and Introduction of E. C. Greco by T. P. May 1:40 pm Opening Remarks by E. C. Greco, NACE President. 2:00 pm Corrosion of Steel as Influ-enced by Its Composition and Environment by C. P. Larra-

3:00 pm Soil Box Demonstration of Cathodic Protection by M. C. Miller.

Tuesday, November 28
9:30 am Stress Corrosion of Cast Aluminum Alloys by Fred M. Reinhart.

10:20 am Effect of Some Trace Elements on Stress Corrosion Cracking of Stainless Steel by Frances S. Lang. 11:10 am Armco 17-4 PH High Strength

Stainless Steel by J. J. Hal-

1:30 pm The Corrosion Engineer's Choice of Plastics by Otto H.

2:20 pm Coating Structural Steel Be-fore Erection by R. J. Koch. 3:10 pm Austenitic Nickel Cast Irons

in Petroleum Industry by T. P. May, W. K. Abbott and J. F. Mason, Jr. 4:00 pm Sea Water Conversion Processes by W. S. Gillam.

### Wednesday, November 29

9:30 am Corrosion Resistance of Stranded Steel Wire in Sea Water by Jane H. Rigo. 10:20 am Effect of Cathodic Protection

on Corrosion Fatigue of Ship Plate in Salt Water by M. H. Peterson, L. J. Waldron, E. P. Dahlberg and B. F. Brown.

11:10 am Stress Corrosion of Aluminum-Magnesium Alloys by Lee Craig.

Afternoon Open to visit displays.

### Thursday, November 30

9:30 am Coatings and Sealants for Fuel Storage Tanks by J. E. Cow-ling, J. R. Griffith and A. L. Alexander.

10:20 am Some Present and Future As pects of Inorganic Coatings by D. H. Gelfer,

11:10 am Coatings Tests on the Key West Aqueduct by E. P. At-

1:30 pm Cathodic Protection-Continuous Measurement and Auto-matic Control by L. P. Sud2:20 pm Effect of Cathodic Protection on Corrosion Fatigue of Stee Sea Water by J. L. Nichols

3:10 pm Mitigative Measures Applied to Underground Lead Sheathed Cables and Asso-ciated Hardware by A. L.

Ayres.
4:00 pm Thirty-Seven Years of Cooperation—The Louisville Join Electrolysis Committee by Stuart H. Gates.

9:30 am Role of Grounding Cells and Similar Devices in Effective Cathodic Protection of Lead Sheathed Power Cables of Substation Exit Systems by Sidnay F. Trough and Morting Sidney E. Trouard and Martin

J. Maier. 10:20 am Ablative Materials and Mech-

anisms by I. T. Turner. Evaluation of Protective Coat-11:10 am ings at Brandenton, Florida, Sewage Treatment Plant by Perry Cessna.

### Canadian Region

### Calgary to Host 1962 Western Conference

The Calgary Section will host the Canadian Region's 1962 Western Division Conference. This meeting will be held in February at the Pallister Hotel in Calgary.

Conference chairmen have been elected and are working on the arrangements. These men are General Chairman G. C. Mainland of Imperial Oil Ltd., Secretary S. N. Gell of Canadian Western Natural Gas, Technical Program Chairman J. U. Messenger of Mobil Oil of Canada Ltd., Entertainment and Arrangements Chairman A. W. Dinnigan of British America Paint Company Ltd., Planning and Exhibits Chairman H. T. Andersen of Canadian Western Natural Gas and Publicity Chairman J. S. Watson of Interprovincial Corrosion Control Company. Conference chairmen have been elect-

Vancouver Section has arranged its fall Vancouver Section has arranged its fall program. All meetings will be held in conference rooms of the Sands Motor Hotel at 6:30 pm. On September 21 the section scheduled J. Peters of Industrial Formulators of Canada, Ltd., to speak on Epoxies—Practical Aspects of Formulating With Respect to Coatings Formulating With Respect to Coatings and Adhesives. On Octover 19, Miss Sophie Laddy of the Science and Technology Department, Vancouver Public Library, will give a talk titled How a Trained Librarian Can Help You Make Use of Technical Literature. On November 16, R. D. Barer of Pacific Naval Laboratory, Esquimalt, will speak on Boiler Corrosion and Metallurgical Aspects of Boiler Tube Failures.

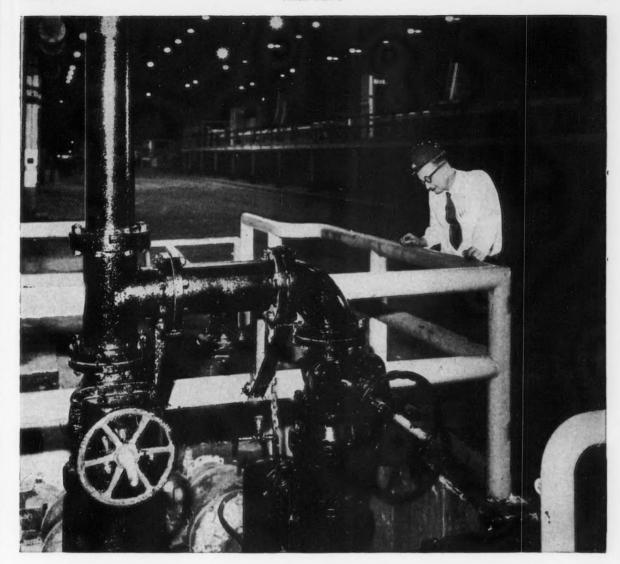
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# SARAN LINED PIPE carries 50,000,000 gallons of hot H<sub>2</sub>SO<sub>4</sub> solution—no failure after 7 years!

After seven years of constant use ... carrying 100° F. dilute sulphuric acid ... a 600-foot pipeline of 6-inch Saran Lined Pipe is still in original condition, without a single failure or replacement. The line carries up to 3% sulphuric solution from pickling lines to disposal units at United States Steel Corporation's Fairless Works, Morrisville, Pa.

"Our Saran Lined Pipe has carried over 50,000,000 gallons of dilute sulphuric in seven years," says Mr. C. R. Fritz, General Foreman. "400 feet of this 6-inch line are on an inside wall, supported by vertical pipe hangers. The remaining 200 feet are underground. We haven't had to replace a single foot of it since the plant began operations."

Sarar Lined Pipe and fittings give double protection for processing operations . . . saran lining provides high resistance to corrosion, and the tough steel casing has great strength and rigidity. Saran Lined Pipe requires a minimum of support, even for long horizontal runs, reducing installation time and costs.

Saran Lined Pipe, fittings, valves and pumps are available for systems operating from vacuum to 300 psi, from below zero to 200° F. They can be cut, fitted and modified easily in the field without special equipment. For more information, write Saran Lined Pipe Company, 2415 Burdette Avenue, Ferndale, Michigan, Dept. 1562AU10.

THE DOW CHEMICAL COMPANY



Midland, Michigan

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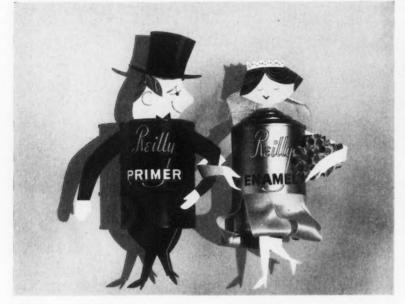
### **North Central Region**

### 23 Firms Holding Space For St. Louis Exhibition

Twenty-three companies are reserving space for the "Exhibits in Miniature" to be held in conjunction with the North Central Region Conference at the Chase Hotel in St. Louis October 9-11, 1961. Technical program, including abstracts, appear in May Corrosion, Pages 50-51. Companies planning exhibits are as

Orchard Paper Company Nooter Corporation The Pfaudler Company

St. Louis Metallizing Company Missouri Boiler & Tank Company The Duriron Company Amercoat Corporation Standard Pipeprotection, Inc. National Carbon Company Carboline Company Van Devanter Engineering Company Industrial Process Equipment Co. Monsanto Chemical Company American Zinc Sales Company Nalco Chemical Company Davies Supply & Manufacturing Co. A. O. Smith Corporation Johns-Manville Corporation Galloway-Ratcliffe, Inc. Geigher Pipe & Supply, Inc. Sperry Products Company Wisconsin Protective Coating Co. Wright Chemicals Company



# TOGETHER FOR GOOD

Reilly Coal Tar Enamels and related primers, used together, provide the corrosion protection needed by underground metal structures. The Reilly hot enamel system is:

electrically insulated waterproof oilproof bacteriaproof

oxidationproof stressproof tough and strong permanently bonded

In addition, Reilly coating systems offer ultimate longevity because they inherit the chemical inertness and stability of coal tar, from which they are made.

Specify Reilly hot-applied coal tar enamels and related primers for oil, gas and water pipelines.

### REILLY ENAMEL AND PRIMER

Reilly Pipeline Enamel Reilly Intermediate Enamel Reilly 230-A Enamel Reilly 230 AWWA Enamel

Reilly Pipeline Primer Reilly QD Primer Reilly 230 X-10 Primer Reilly 230 X-10 Primer

Reilly **Redhead®** Primer

Reilly Hot Service Enamel

Reilly 230 X-10 Primer

### REILLY TAR & CHEMICAL CORP.

1615 MERCHANTS BANK BUILDING, INDIANAPOLIS 4, INDIANA



### Hoxeng Appointed Member Of Research Committee

R. B. Hoxeng has been appointed a member of the NACE Research Committee. Also a member of the Young Author Award Committee, Hoxeng is director of research, American Steel & Wire Division, United States Steel Corporation, Rockefeller Building, Cleveland 13, Ohio.

Twin Cities Section has scheduled M. E. Nicholson of the University of Minnesota to discuss "A Seminar on Corrosion Principles" for its October 10 meeting at the Calhoun Beach Hotel, Minneapolis.

For its September 12 meeting the section scheduled a talk on zinc alloys by Charles W. Ambler, Jr., of American Zinc, Lead & Smelting Company.

Meetings are set for November 14,

December 12 and January 9.



#### October

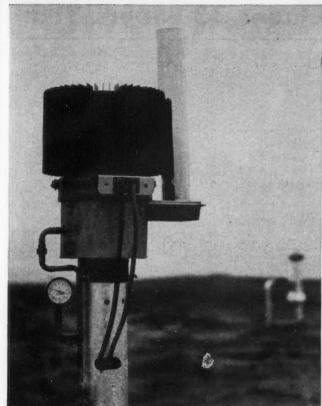
- 10 Montreal Section
- Twin Cities Section, Seminar on Corrosion Principles by M. E. Nicholson of U. of Minn.
  Tidewater Section
- Pittsburgh Section, Railroad Tracks and Structures by C. J. Code of Penn. Railroad
- Alamo Section
- Chicago Section, Reference Electrode Measurements and Cathodic Protection by G. C. Wilson of Institute of Gas Technology.
- Vancouver Section, How Trained Librarians Can Help You Make Use of Technical Literature by Miss Sophie Laddy of Vancouver Public Library.
- Philadelphia Section, Fundamentals of Corrosion by Robert Jelnick of Syracuse University
- 30 New Orleans Section

### November

- Teche Section
- West Kansas Section
- Pittsburgh Section, Corrosion of Exterior Automotive Trim by G. F. Bush of Ford Motor Company
- Central Oklahoma Section
- Houston Section, Student Night, Hydraulic Spray Application of Fiberglass Reinforced Epoxy and Polyester Resins by Moody Adams of Matcote.
- Twin Cities Section
- Wilmington Section, Protective Coating by James E. Parkinson of U. S. Navy Yard.
- Vancouver Section, Boiler Corrosion and Metallurgical Aspects of Boiler Tube Failures by R. D. Barer of Pacific Naval Laboratory.
- Alamo Section
- Chicago Section, Half a Century of Research in Glass by J. W. McClellan of Corning Glass Works
- New Orleans Section

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is &



Thermoelectric generator protecting well casing in the Hugoton Field.

CARLA's 60 to 70 mph winds failed to extinguish the flame on a sister unit on test in Houston.

# Again, CPS Is In There Fustest With The Mostest ...

in the form of a field tested thermoelectric generator which is in production and available at moderate cost

As a result of the joint design and development efforts of Texas Instruments, Incorporated and Cathodic Protection Service over the past year we are happy to announce to the corrosion engineer the availability of a field-tested and proven thermoelectric generator. This unit described herein is not a laboratory model or a prototype but is a unit which is now in commercial production and is ready for practical applications of cathodic protection in the field.

This generator which has no moving parts produces currents from lead telluride thermocouples which convert heat directly to electric energy. This, the "guts" of the unit, has gone through extensive shakedown tests in the Texas Instruments laboratories for the better part of the developmental period.

The lead telluride system is built into a housing consisting primarily of a burner capable of using either natural gas or LPG as the fuel and an efficient heat dispensing unit. The complete production model of the generator has been exhaustively tested both in our shops and in an actual field installation providing current for the cathodic protection of a well casing.

To be assured of continuous operation under all types of climatic conditions in the field the burner for the production line model has been designed to withstand wind velocities in excess of 100 mph by actual test.

First attention has been given to the development of a unit of 8 watts capacity, a rating capable of covering a large number of cathodic protection applications, particularly in the field of protection of well casings. This is the unit which is in large scale production but represents only the first of a series of generators which will meet nearly all cathodic protection applications. Additional capacities will be anounced in the near future.

The present production model is particularly suitable for the protection of well casings of moderate current requirements, extensive hot spots on bare gas pipe lines, and also for furnishing supplemental power for the protection of coated pipe lines and heater treaters or other salt water handling equipment, just to name a few of the potential applications for this commercially available unit.

CPS is the sole outlet for this jointly developed unit as applied to the cathodic protection field. Contact our main office in Houston or any of, the below-listed branch offices for operating data and cost information.

### **Cathodic Protection Service**

P. O. Box 66387 Houston 6, Texas JA 6-1981 CORPUS CHRISTI TUlip 3-7264 1620 S. Brownlee LOS ANGELES 7531 Muller St., Downey Phone TO 2-2045 **NEW ORLEANS** 1627 Felicity JAckson 2-7316 5425 Andrews Hwy. EMerson 6-6731 **PITTSBURGH** 4 Delmar Ct., Delmont HO 8-7513 2570 S. Harvard RIverside 2-7393

# New York Program Includes 33 Papers, Tours

### Anodic and Cathodic Lectures Also Set

Complete technical program has been set up for the Northeast Region Conference at the Statler Hilton Hotel, New York City, October 30-November 2. Abstracts of 33 papers to be presented are listed below by symposia. Dates and times of symposia are indicated also cated also.

Eight symposia to be held are Power Generation and Transmission, Saline Water Conversion, Plastics, Heat Exchangers, New Metals, Protective Coatings, Protective Linings and Evaluation Tools. Two lectures on cathodic and anodic protection are scheduled under the educational lecture series.

General Chairman for the conference is Russell E. Gackenbach of American Cyanamid Company, New York, N. Y. Technical Program Chairman is Emil G. Holmberg of The International Nickel Company, Inc., New York, N. Y. Symposia chairmen and authors are listed in technical program below.

The technical program is as follows:

#### Monday, October 30 9-12 am

## Symposium on Power Generation and

Chairman, Frank E. Kulman of Consolidated Edison Company, New York, New York.

Corrosion Protection in Power Plants by B. J. Philibert of Pittsburgh Chemical Company, Printert or Pittsburgh Chemical Company,
Protective Coatings Division, Baltimore, Md.
New protective coatings coupled with improved
preparation and application methods provide better corrosion protection for hydraulic structures,
conduits, waste systems and other wetted areas
in power plants.

Pipe Type Cable Corrosion Practices by J. C Howell of Public Service Electric & Gas Com-pany, Maplewood, N. J.

pany, Maplewood, N. J.

General discussion of corrosion controls of an electric utility with five pipe-type cable circuits in operation and a sixth in process of completion. Soil surveys including nuclear probes, thermal needles and soil sampling are discussed. Also discussed are determination of coating resistance by section-to-section process and correction of coating faults. Cathodic protection problems of coated pipe type cable system and other coated pipe lines are compared.

Corrosion Survey Techniques on Underground Pipelines by A. W. Peabody of Ebasco Services, Inc., New York, N. Y.

tees, Inc., New York, N. Y.
Reviews objectives of corrosion surveys on underground pipelines. Outlines survey requirements for bare pipelines versus coated pipelines. Covers pipe-to-soil potential, line current, coating resistance, soil resistivity surveys, bacteriological investigations, bellhole investigations and cathodic protection current requirement tests.

Aluminum Pipelines by M. E. Carlisle, Jr., of Aluminum Company of America, New Ken-sington, Pa.

Discusses engineering design considerations and new installation techniques for buried and off shore aluminum pipelines. A 15-minute movie showing recent installations will be shown.

#### Monday, October 30 2-5 pm

#### Educational Lecture

Chairman, George T. Paul of The International Nickel Company, Inc., New York, N. Y.

Cathodic Protection by L. P. Sudrabin of Elec-tro Rust-Proofing Corporation, Belleville, N. J. Every environmental condition influencing a specific electrochemical corrosion system affects response to applied current. Accumulation of applied current ampere hour effects often alters

corrosion system on steel surfaces and characteristics of metals that owe their normal resistance to passive films.

Anodic Protection by Walter A. Mueller of Pulp & Paper Research Institute of Canada, Montreal, Canada.

Montreal, Canada.

Analysis of polarization curves reveals partial currents of oxidizing or reducing reactions which control corrosion of metals in electrolytes. To discuss measuring methods of polarization curves at constant or variable conditions. Present concepts of passivity and of properties of passive films will be surveyed.

### Tuesday, October 31 9-12 am

# Symposium on Heat Exchangers Chairman, G. Sorrell of The M. Y Kellogg Company, New York, N. Y

Brackish Cooling Water Corrosion of Refinery Heat Exchangers by D. B. Bird and K. L. Moore of Tidewater Oil Company, Manufac-turing Department, Delaware City, Del.

turing Department, Delaware City, Del. Severe corrosion of exchangers using brackish cooling water can result if incorrect alloys are selected, if process side temperatures or heat flux is high or if cooling water velocities and scale formation are not carefully controlled. Seasonal variations of cooling water salinity and temperature are given together with effect of temperature changes on exchanger cooling water velocities.

Process Side Corrosion Problems—Heat Exchangers in Chemical Process Industry by Oliver W. Siebert of Monsanto Chemical Company, Organic Chemicals Division, Monsanto, Ill.

santo, III.

Reviews process side corrosion of heat exchangers in chemical process industry. Experience covers units of cast iron, steel, non-terrous metals, ferrous and non-ferrous alloys and noble metals. Environments covered by survey include organic and inorganic acids, bases and their salts, gas and liquid. Equipment types are conventional exchangers, interchangers and condensers.

Corrosion and Scale Deposition on Heat Transfer Surfaces by Herman Kerst of Dearborn Chemical Company, Chicago 9, Ill.

Corrosion, 16, 523t (1960) on laboratory study of corrosion and scale deposition on water side of heat exchange surfaces in presence of high process side temperatures.

Some Practical Considerations for Controlling Corrosion in Salt Water Cooling Systems by Walter S. Janssen of American Oil Company, Texas City, Texas City, Texas City, Texas City and Consoling Property of Property Property of Property National Conference of Property National Conference of Property National Conference of Property of Property

Symposium on New Metals
Chairman, D. B. Dik of Titanium
Metals Corporation of America, New York, N.

Laboratory Corrosion Tests of Columbium by Donald L. Macleary of E. I. du Pont de Nemours & Co., Pigments Department, Wilmington, Del. Columbium, closely related to tantalum, exhibits similarly low corrosion rates in hot mineral acids, organic acids, chlorides and caustic from dilute to concentrated solutions. Corrosion data are discussed in relation to actual and potential commercial applications of columbium metal and alloys.

Titanium Corrosion in Warm, Moist Chlorine Gas by S. M. Weiman of Titanium Metals Corporation, Henderson, Nev.

Titanium has excellent corrosion resistance to warm, moist chlorine gas. However, if a chlorination reaction is induced by severe or unfavorable circumstances in one portion of a titanium structure, the reaction product may cause corrosion in cooler downstream portions of the structure. Qualitative tests describing this phenomenon are presented.

Corrosion of Beryllium Metal by John R. Steele of The Beryllium Corporation, Reading, Pa. Although quite stable in air and in some liquids at room temperature, beryllium does not possess sufficient corrosion resistance under all conditions. Increased usage of the metal has resulted in significant studies of beryllium impurity analysis and various protective systems including cladding, electroplating and vapor metal deposition.

Application of Zirconium in Chemical Plant Service by John H. Schemel of The Carborundum Metals Company, Akron, N. Y. Zirconium has outstanding resistance to many process solutions, especially those containing high concentrations of sulfuric or hydrochloric acid at elevated temperatures. Installation of zirconium equipment should be preceded by careful in-plant testing and sound engineering design of equipment.

# Tuesday, October 31 2-5 pm

Symposium on Protective Coatings Chairman, R. P. Devoluy of T Glidden Company, New York, N.

Glidden Company, New York, N. Y.
Corrosion Through Pores in Protective Coatings
by F. L. LaQue of The International Nickel
Company, Inc., New York, N. Y.
Discusses fundamental factors that determine
extent of corrosion that may occur at bases of
pores or other discontinuities in protective
coatings. These factors include thickness of
coating, nature of coating, surface under coat
ing, volume and conductivity of electrolyte involved in corrosion reaction and galvanic relations between basic metal, coating and other
metals involved in the arrangement.

Urethane Coatings for Corrosive Exposure by Edward R. Wells of Mobay Chemicals Company, New Martinsville, W. Va. Discusses characteristic properties of polyurethane coatings, particularly two-can systems. Data are presented mostly from chemical and solvent resistant tests run in laboratory evaluations against currently accepted types of corrosion resistant coatings. Successful applications are described.

Maintenance of Coast Guard Aids to Navigation System by D. C. Klingensmith, U. S. Coast Guard Headquarters, Washington 25, D. C. Discusses vinyl coatings for buoys and maintenance cycle. Outlines coatings for both masonry and steel fixed structures, including lighthouses and offshore structures.

Recent Developments in Epoxy Resin Coatings by John Klorquist of Shell Chemical Company, Union Laboratories, Union, N. J. Describes solventless epoxy system which can be applied with conventional spray equipment. Advantages of this system are high film build per coat, greatly reduced fire hazard and good resistance to many fuels and chemicals.

## Wednesday, November 1 9-12 am

Symposium on Saline Water Conversion Chairman, W. S. Gilliam of Division of Research, U. S. Department of In-terior, Office of Saline Water, Wash-ington 25, D. C.

Corrosion Control Cuts Conversion Costs by F. W. Fink of Battelle Memorial Institute, Columbus, Ohio.

Reviews effects on sea water conversion plants of such factors as velocity, heat transfer, biofouling and scaling. Also discusses design and environmental control measures.

Corrosion Evaluation Tests in Demonstration Plants by R. H. Jebens of U. S. Department of Interior, Office of Saline Washington 23, D. C.

Saline water demonstration plants will provide an excellent opportunity to obtain corrosion (Continued on Page 74)

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**Social Calendar** for **Northeast Conference** 

Tuesday, October 31 **Noon Luncheon** 

Wednesday, November 1 **Evening Social Hour**  ıt o-

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# PENTON\* at work: PFAUDLON 301



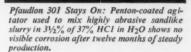
# The modern corrosion barrier for process tankage

Pfaudlon 301 is the name of a watersuspension coating based on Penton which provides an economical way to protect equipment from the corrosive effects of direct product contact with corrosive fluids and atmospheres.

Resistant to more than 300 different chemicals and chemical reagents Pfaudlon 301-Penton coatings are hard, nonporous, glossy and smooth. They can be readily applied as an interior or exterior coating to such metals as mild steel, cast iron, stainless steels, Hastelloys, brass, bronze or copper.

Pfaudlon 301 coatings can serve on many kinds of equipment—storage tanks, open vessels, hoods, blowers, ducts, baskets, pump and pump parts. Pfaudlon 301-Penton coatings can be supplied by Pfaudler on new process equipment, or applied on existing equipment as a custom coating by Pfaudler-licensed applicators in your area.

Pfaudion 301 coatings are but one of the many ways in which Penton, the modern engineering thermoplastic, is now serving industry in combating corrosion of many types. Penton processing components of all types are now readily available. Write for your copy of "The Penton Buyer's Guide," a complete listing of suppliers of valves, pipe and fittings, pumps, meters, tank linings and coated parts made with this low cost, durable, and reliable corrosion barrier.





Simple as ABC. Send for The ABC's of Penton for Corrosion Resistance. This bulletin rates Penton's performance at temperatures up to 250°F. when exposed to over 300 chemicals and reagents.



\*Penton is the Hercules Powder Company registered trademark for chlorinated polyether.

HERCULES POWDER COMPANY

Hercules Tower, 910 Market Street, Wilmington 99, Delaware

For information on Pfaudlon 301 coatings for new or existing process equipment, write: Pfaudler Permutit, Inc., Rochester, New York.

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#### **New York Program**

(Continued From Page 72)

data for water under many conditions. Distilla tion processes become more economical if higher operating temperatures can be used. Corrosion test samples and various materials of construction will be used in an effort to obtain data for future plant construction.

Methods of Studying Corrosion by Saline Water by Norman D. Groves of Carpenter Steel Company, Reading, Pa.
Use of such methods as electrochemical measurements, potentiostatic measurement, resistance probes and controlled velocity methods to study effect of saline water on candidate materials of construction are reviewed and compared. Presented are comparative data on iron base, nickel base and copper base materials of construction. Velocity effects on corrosion data are reviewed.

Experience with Materials in Sea Water Service by Thomas P. May of The International Nickel Company, Inc., Wrightsville Beach, N. C.
Use of many types of valves and pumps at Harbor Island (Kure Beach) Corrosion Laboratory provides much useful information for reference in selection of materials for plants where corrosion by sea water is a factor.

Symposium on Plastics
Chairman, Byron I. Zolin of E. I.
du Pont de Nemours & Company,
Engineering Department, Wilmington Del

Reinforced Plastic Equipment for Process In-dustry by Fred W. Arndt of Heil Process Company, Cleveland, Ohio. Discusses increase in size and complexity of process equipment made from glass reinforced polyester resin laminates. Describes some new reinforced plastics applications.

reinforced plastics applications.

New Piping Materials for High Temperature Corrosion by Robert T. Crouch of Johns-Manville Products Corporation, Research Center, Manville, N. J.

Describes new line of a sbestos reinforced thermosetting resin pipe and fittings manufactured by Johns-Manville. Called Chemitie, the products are made from crysotile (white) or crocidolite (blue) asbestos fibers and epoxy or phenolic resins. In-service field testing shows materials have excellent resistance to many acids, alkalies, salts and organic steams to 300 F.

300 F.
Flammability Testing of Reinforced Polyester Equipment by Seymour S. Feuer and Alan P. Torres, Atlas Chemical Industries, Inc., Wilmington, Del.
Lack of standardization exists in methods for measuring and specifying fire resistant requirements. During development of a fire retardant, corrosion resistant polyester resin designed to be used in production of fiber glass reinforced equipment, an attempt was made to determine flammability requirements for fume ducts and hoods. Radiant panel test data will be discussed.

"Delrin" Acetal Resin Pipe—A New Engineering Material by J. F. Cogdell of E. I. du Pont de Nemours & Company, Technical Services Laboratories, Wilmington, Del. "Delrin" pipe-has two outstanding properties: High fatigue endurance limit to pressure surging and outstanding solvent resistance. Also it possesses high strength and toughness. Joining is a simple heat fusion process on a 25-second cycle to give an integral leak free joint. Discusses product as design material for corrosion engineers.

Wednesday, November 1 2-5 pm

Thursday, November 2 9-12 am

Symposium on Protective Linings Chairman, Kenneth Tator of Kenneth Tator Associates, Coraopolis, Pa.

Problems Confronting Manufacturers of Protective Linings and Coatings by G. Karl Vogelsang of Gates Engineering Company, Wilmington, Del.
Problems of manufacturers of protective linings and coatings relate not only to raw materials with respect to prices, quality and uniformity but to quality control, packaging and plant safety. Proving out new raw materials and processes is a continuing process. Continuous research programs are necessary to maintain competitive positions and to make available improved products and products to meet new situations. situations

What Are Your Specifications Costing You? by Kenneth G. LePevre of Metalweld, Inc., Philadelphia, Pa. Discusses obligation of corrosion engineer to see that his specifications are met. Actual case histories and cost data readily available prove that writing good, tight specifications is not enough.

Tank Lining and Surface Preparation Nemeses by Oliver W. Siebert of Monsanto Chemical Company, Monsanto, Ill., and Otto H. Fenner of Monsanto Chemical Company, St. Louis, Mo.

Louis, Mo. Discusses evaluations of unsatisfactory experiences with tank lining applications for corrosive services in chemical industry. Reviews causes of failures in light of surface preparation and prime coating difficulties rather than considerations of incompatibility of top coatings to specific environments. Remedial specifications are given

Panel Discussion

Symposium on Evaluation Tools
Chairman, Harold C. Templeton of
Alloy Steel Products Company, Linden,

Importance of Basic Inspection Methods by John Abramchuk of Atlantic Refining Com-pany, Philadelphia, Pa.

Many excellent inspection tools have evolved from recent advances in electronic, ultrasonic and nuclear technology. However, simple hand tools are still important. Discusses briefly techniques used in visual inspections, hammer testing, calipering, pressure testing, bench marks and drilling.

and Grilling.

Industrial Radiography by Charles J. Veith of E. I. du Pont de Nemours & Company, Engineering Department, Wilmington, Del. Covers basic principles of industrial radiography, factors affecting its quality, penetrametry and interpretation of radiographic film.

Modern Methods of Nondestructive Testing with Magnetic Particles and Fluid Penetrants by Henry G. Bogart of Magnaflux Corporation, New York, N. Y. Magnetic particle and fluid penetrant methods are basically simple but there are many fine points and techniques, equipment, materials and interpretations which are important to successful application of these methods.

ful application of these methods.

Ultrasonic Methods of Inspection by John Bobbin of Branson Instruments, Inc., Stamford, Conn.
Deals with use of ultrasonic techniques for inspecting process equipment and pipe lines to detect such effects as reduction in wall thickness from corrosion and erosion and metallurgical changes such as presence of hydrogen attack and general flaws. Gives explanation and comparison of basic instrumentation in application thicknesses now in use including recent developments for high temperature on-steam inspection.

## N. Y. Stock Exchange On Tour Schedule Wednesday Afternoon

Three interesting tours are in store for those attending the Northeast Region Conference at the Statler Hilton Hotel, New York City, October 30-November 2.

New York City, October 30-November 2. Scheduled for Wednesday afternoon, November 1, between 2 and 5 pm as part of the technical program are tours of Consolidated Edison Company's generating station across the river from Manhattan in Queens at Astoria, N. Y. Manhattan in Queens at Astoria, N. Y., the Hayden Planetarium and the New York Stock Exchange.

Generating Station

Consolidated Edison's generating station at Astoria has a one million-kilowatt capacity; it is the company's largest plant and probably the largest on the East Coast

This tour begins with a briefing in the plant's conference room. The tour then proceeds to the top of the station where the tour route can be observed, which includes the dock for barges and tankers, screen house, boilers, turbines, chemical treatment area and laboratories.

Hayden Planetarium

This tour begins in the Hall of the Sun in which is suspended a 48-foot model of the solar system. Visible planets and many satellites will be seen in fluorescent or black light that creates the illusion of motion in space. will be a presentation entitled Design of the Universe; this presentation will be in the dome room where the Zeiss Projector is installed and will deal with several recent theories developed to expense. plain how the universe came into being and how it may eventually evolve.

New York Stock Exchange

This tour includes a lecture and a visit to the various industrial exhibits and to the gallery overlooking the trad-

> **Technical Committees** To Meet at Conference Appear on Page 61

### LET **COLECO** WORK FOR YOU 24 HOURS A DAY TO PROTECT YOUR PIPELINES AND OIL WELL CASINGS AGAINST COSTLY CORROSION



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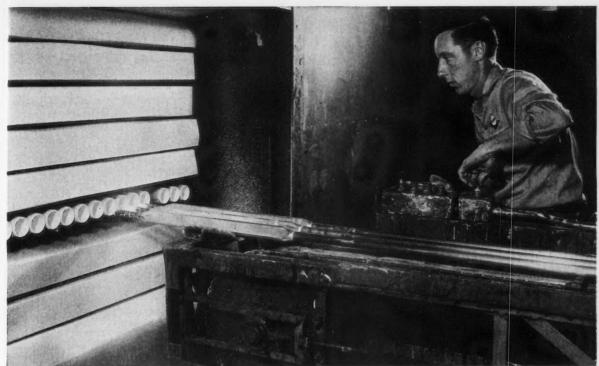
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Plastic Applicators uses specially designed spraying lances to apply uniform plastic coatings.

# Why do some pipe coatings outlast others?

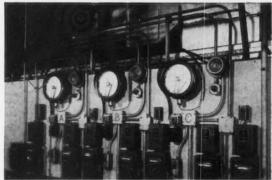
One reason is that some plastic formulations are superior to others.

Another less obvious (but often more important) reason is that some coating applicators use more effective application and quality-control methods than others. These better methods produce more durable coatings that make your pipe last longer.

At Plastic Applicators, we apply Plasticap coatings only to carefully sandblasted, metal-clean pipe surfaces, using the unique application equipment shown above. Plastic Applicators engineers designed these efficient spraying lances to apply consistently uniform plastic coatings to pipe placed in baking ovens. To prevent moving the pipe before each successive coating has been applied and baked, our engineers designed a special conveyor mechanism to move the lances from oven to oven.

Another part of the answer to effective quality control at the four Plastic Applicators plants is in the process-control equipment shown below. The optimum time and temperature for each baking cycle are precisely programmed by these control devices to produce exactly the same result each time an ovenload of coated pipe is baked.

You can put these important quality-control procedures to work for you by specifying long-lasting



Plasticap coatings for your pipe. Call your nearest Plastic Applicators representative today for prices and delivery schedules.

#### **LOCATIONS:**

Main Office: 7020 Katy Road, P. O. Box 7631, Houston, Tex., UN 9-3611. Plants: Harvey and Morgan City, La.; Houston and Odessa, Tex.

Sales Offices: Midland and Corpus Christi, Tex.; Hobbs, N.M.; Tulsa, Okla.; Houma, Lafayette, New Orleans, and Shreveport, La.; Jackson, Miss.



PLASTIC APPLICATORS, INC.

# Northeast Region

# Pittsburgh Arranges Program Through May

Pittsburgh Section has scheduled its program through May, 1962. The program is as follows:

October 12—Corrosion Problems—Railroad Tracks and Structures by C. J. Code of Pennsylvania Railroad Company.

November 2—Corrosion of Exterior Automotive Trim by G. F. Bush of Ford Motor Company.

December 7—Underground Corrosion Round Table. Chairman: C. A. Erickson of Peoples Natural Gas Company.

January 4—Corrosion of Steels in Nuclear Power Reactors by A. L. Medin of United States Steel Corporation.

February 1—Coatings Round Table. Chairman: John D. Keane of Steel Structures Painting Council. Panel: Surface Preparation by Joseph Bigos of United States Steel Corporation. Application and Costs by Ludwig Adams of Virginia Erection Company. Anti-Corrosive Paints by Kenneth Tator of Kenneth Tator Associates.

March 1—Current Water Treatment Practices: Boiler Water by W. M. Sonnett of Dearborn Chemical Company. Cooling Towers by R. G. Dalbke of Dearborn Chemical Company.

April 5—Plant Tour of Mathies Mine, Pittsburgh Coal Company.

May 25—Ladies Night: Dancing and midnight supper at Pittsburgh Field Club.

Lehigh Valley Section met September 19 in Reading at the Mountain Springs Association as guests of The Glidden Company. Officers for the coming year are Chairman Donald H. Gittleman, Vice Chairman and Program Chairman James P. Snyder, both of The Glidden Company, Third and Bern Streets, Reading, Pa., and Secretary-Treasurer John A. Singer, Jr., of C. K. Williams & Company, 640 North 13th Street, Easton, Pa.

Philadelphia Section has scheduled Robert V. Jelinek of Syracuse University to speak on Fundamentals of Corrosion at its October 27 meeting at The Poor Richard Club, 1319 Locust Street. Coffee speaker will be L. Loyd Bohn of Temple University who will discuss tests to determine the authenticity of old paintings. This will be Students' Night; the Drexel Evening School Alumni Association has been authorized to bring 20 students. Dinner charges have been increased from \$4\$ to \$4.50. The Governing Board reports the section now has 237 members. The projected short course was discussed at the board's meeting August 7.

Kanawha Valley Section has voted to invite two students and one faculty member from local schools to attend each of the sectional meetings during the 1961-62 season. A committee has been formed to issue invitations. Chairman of this committee is George C. Cox and members are A. W. Horne, R. G. Schroder and L. S. Van Delinder.

The section also has appointed R. P. Ballard Publicity Chairman, C. C. Stoneking and R. L. Davisson Program Chairmen and L. T. Moore Membership Chairman.

On September 21, the section heard John Lomax of Hercules Powder Company, Wilmington, Del., speak on Field Experiences With Corrosion Resistant Penton Coatings and Linings. This meeting was held at Stone Lodge Restaurant, Huntington, W. Va.

# MATIONAL and REGIONAL MEETINGS and SHORT COURSES

#### 1961

Oct. 4-6—Western Region Conference, Benson Hotel, Portland, Oregon.

Oct. 9-11—North Central Region Conference, St. Louis, Chase Park Plaza Hotel.

Oct. 24-26—South Central Region Conference and Exhibition, Shamrock-Hilton Hotel, Houston.

Oct. 30-Nov. 2—Northeast Region Conference, New York City, Hotel Statler.

Nov. 27-Dec. 1—Southeast Region Conference and Florida General Conference Short Course, Key Biscayne Hotel, Miami, Fla.

Nov. 29-30—NACE Board of Directors Meeting, Key Biscayne Hotel, Miami, Fla,

#### 196

January 17-19—Canadian Region Eastern Division Conference, King Edward Hotel, Toronto, Ontario.

March 18—NACE Board of Directors Meeting, Muehlebach Hotel, Kansas City, Mo.

March 19-23—18th Annual Conference and 1962 Corrosion Show, Kansas City, Missouri, Municipal Auditorium.

March 23—NACE Board of Directors Meeting, Muehlebach Hotel, Kansas City, Mo.

October 1-4—Northeast Region Conference, Hotel Sheraton Ten Eyck, Albany, N. Y.

October 9-11-North Central Region Conference,

October 11-12—Southeast Region Conference, Birmingham, Ala.

October 16-19—South Central Region Conference and Exhibition, Granada Hotel, San Antonio.

#### 1963

March 18-22—19th Annual Conference and 1963 Corrosion Show, Convention Hall, Atlantic City, N. J.

October 14-17—South Central Region Conference, Oklahoma City, Okla.

October 22-24—Northeast Region Conference, Niagara Falls, N. Y.

#### 1964

March 9-13-20th Annual Conference and 1964 Corrosion Show, Sherman Hotel, Chicago, Ill.

October 25-30—North Central Region Conference, Hotel Lemington, Minneapolis, Minn.

#### 1965

March 15-20—21st Annual Conference and 1965 Corrosion Show, Chase-Park Plaza Hotel, St. Louis, Mo.

#### SHORT COURSES

#### 1962

Feb. 21-23—12th Annual Corrosion Short Course, Tulsa, Okla.

#### Three Slide Shows Available

Three 35mm color slide shows are available free to NACE Sections and other interested groups for program use. The three slide sets, described below, are accompanied by scripts for oral comments as the slides are shown.

1. 17th Annual NACE Conference and 1961 Corrosion Show: 72 color slides showing main activities of conference plus close-up views of many booths at the Corrosion Show. Suggested as good survey of conference for persons who did not attend the Buffalo meeting. Program time: 30 to 45 minutes.

2. Surface Preparation by Sandblasting: 18 color slides showing various specifications of sandblasting for sur-

face preparation. Copies of technical paper by E. W. Oakes are sent with slide set. Specify number needed. Program time: 20 to 35 minutes.

3. 1960 Corrosion Show: 102 slides showing many of the booths and some of the products exhibited during the conference held last year in Dallas. Program time: 30 to 45 minutes.

Persons or groups interested in using the slide sets should send booking requests as far in advance as possible to Durwood Levy, NACE Central Office, 1061 M & M Bldg., Houston 2, Texas.

Slides can be shown on most standard slide projectors designed to handle 35mm color slides.

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# \$36 worth of Corban helped oil producer save more than \$3000 in six months



Here is a story that shows how the effective low-cost corrosion protection offered by Corban® helped reduce costs and increase net profits for an oil producer. The well was a pumper in Wayne County, Illinois. The operator was plagued with corrosion-caused sucker rod breakage. Sixteen rod partings had occurred in less than eleven months, including rods in a new string which had been in the well about two months. Service costs alone for the fishing and rod-pulling jobs totaled \$1029. This did not include downtime or rod replacement costs.

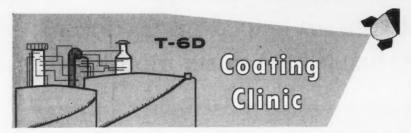
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At last report, \$36 worth of Corban had been used, and there had been no rod failures for six months. Based on past experience, the operator estimated that the \$36 worth of Corban had saved him more than \$3000.

If you have a corrosion problem, call your Dowell representative. He will help you develop an effective, low-cost treatment program designed to reduce operating costs and increase profits. Dowell services and products are offered from more than 150 offices and stations in the United States, Canada, Venezuela, Argentina, Germany, France and the Sahara area. Dowell, Tulsa 1, Oklahoma.

PRODUCTS FOR THE OIL INDUSTRY





If you have a question or problem related to industrial paint applications, NACE Technical Unit Committee T-6D will forward it to qualified men in the industrial coating field for answers and suggested solution to problems. State your problem fully, Questions should be addressed to T-6D Coating Clinic, Corrosion Magazine, 1061 M & M Bldg., Houston 2, Texas.

#### Rotary Versus Piston-Type Air Compressors

What are some advantages of constant air (delivered by rotary-type air compressor) over fluctuating air (as delivered by piston-type air compressors)?

Answer: Both types of machines can and are used for general coating application and surface preparation purposes. It is generally agreed, however, that a smoother, more uniform coating can be applied with the more constant pressure obtained from the new rotary-type machines. The sand-to-air ratio would remain more constant on sandblasting operations, which should permit the operator to adjust his blasting to a uniform rate with some increase in productivity.

#### Sandblasting Tank Roofs

Is it considered a safe practice to sandblast on roofs of storage tanks containing hydrocarbons? If so, please give details as to how this can be done safely.

Answer: Most plants have prohibited the use of sandblasting on roofs of tanks containing flammable products for many years and many still do. There have been different opinions on the heat intensity of sparks generated by sandblasting, the temperature of the steel after prolonged sandblasting in a given spot and the dangers of static build-up from blasting operations. In view of these divergent opinions, the safe course for management and safety departments to take has always been to prohibit sandblasting operations above the liquid level in tanks.

Modern-day operations are such that long downtimes on equipment must be minimized and more and more maintenance work accomplished with equipment in service. Therefore, we can no longer simply take the obvious safe approach but must determine methods and procedures which will permit the accomplishment of necessary work operations in a safe and dependable manner. This was the case concerning the sand-blasting of tank roofs without removal from service. The need was there; the problem was to determine a simple, safe procedure for doing the work.

Tests have indicated, and there is general agreement, that sparks from sandblasting are relatively cool and that their heat is further reduced by the effects of the blasting air. Tests also have shown that skin temperatures will not tend to approach ignition temperatures. Therefore, the chief cause of concern is static electricity build-up.

There are two methods currently being used to sandblast tanks without removal from service. Both methods have the following provisions in common:

- 1. Tanks must be filled to maximum filling height with no pumping in or out while blasting operations are in progress.
- 2. All suction and discharge lines must be closed until blasting operations cease.
- 3. Gas-tight vertical extensions must be placed on tank vents.
- 4. All gauging hatches, corroded areas and other openings must be temporarily sealed by some appropriate method to assure gas-free conditions in the work

5. All sandblast nozzles shall be electrically bonded to the tank shell.

In addition to the provisions listed above, one approach is to electrically bond all items of equipment and the operator to the tank. On floating roof tanks, this includes bonding of roofs to shells.

Another method is always to have a noncombustible mixture in the vapor space of the tank. In this case only the sandblast nozzle is bonded to the tank roof. The gas content within the vapor space of the tank plus any vapor spaces involved with floating roofs, such as inside the pontoons, between double decks and underneath the shell seals, is always maintained either below 20 percent of the lower explosive limit or above 50 percent hydrocarbon gas by volume. This assures that even should a source of ignition occur, no explosion could take place. About the only thing that could possibly happen would be the ignition of a small gas leak on the outside of the roof if an opening was improperly sealed and this could be extinguished easily and quickly. Both natural gas and inert gas generators can be used to obtain the two safe conditions described above.

#### Coating Coverage

Why is it that some coatings will cover the number of square feet stated in the manufacturer's literature and others don't even come close? This causes us a lot of difficulty in bidding jobs with coatings unfamiliar to us and sometimes can mean the difference between profit and loss.

Answer: There is a great need for more standardization in this category. Many large paint companies have traditionally given the theoretical coverage in square feet per gallon one mil thick. This is a true coverage figure only under

ideal laboratory conditions with no loss involved. Other paint companies will deduct a certain loss, such as 10 percent, to give a more practical field figure. But neither of these figures is useful to you unless consideration also is given to the thickness specified. In other words, a coating which shows 400 square feet per gallon on the label at one mil thick will cover only 200 square feet if your specifications call for two mils.

You can calculate these coverages in a realistic manner for yourself if you will ask your paint supplier to give you the percent solids by volume of the coating you are to use. Please note that this figure must be by volume and not by weight. The percent solids by weight has no relation whatsoever to the coverage you will get.

Now, a gallon of anything, if no volatiles are present, will cover 1604 square feet one mil thick. If your coating is 50 percent solids by volume, it will cover 802 square feet one mil thick. If specifications call for applying the coating two mils thick, half the 802 to get 401, which would in this case be your theoretical coverage in square feet per gallon.

But this 401 is still the theoretical coverage, assuming no loss. Deduct from this the anticipated losses, depending on the type of job you are to do. Reasonable deductions are 10 percent for unpitted plane steel such as tank or barge exteriors, 20 percent for structural steel and 4-inch diameter and up piping and 20 percent for poured concrete and concrete blocks. Heavily pitted old steel and rough concrete will require larger deductions; other factors such as high wind conditions will require an extra allowance. And, of course, to get the proper coverages, you must use the correct equipment for the job and have supervision over your men to insure that they use the equipment at maximum efficiency.

#### Coating for SO<sub>2</sub> Fume Area

In an SO<sub>2</sub> fume area at a marine location, we are repainting tanks about every three years. New tanks equipped with steam coils for 125 F operation are soon to be constructed in this area. What would be the most economical coating system to consider for the new tanks under the above conditions?

Answer: Almost any of the thin film, chemical resistant coating systems on scale free steel may extend the coating life beyond three years. However, it is usually more economical to invest initially in an alkyd system of short life and later apply a vinyl, chlorinated rubber or epoxy system at time of the first repainting.

Since reference is made to heated tanks, even greater economy may be realized with the use of a thick film bituminous plastic-type "D" insulation. By savings in fuel as well as longevity, a suitable pay-out period may be realized. Acrylic or vinyl emulsion top coats are applicable when preferred for color.

More than 125,000 two-way radio transmitters are in operation by utility companies in this country.



# CORROSION ABSTRACTS

#### INDEX TO CORROSION ABSTRACTS

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October, 1961

No. 10

#### CHARACTERISTIC CORROSION PHENOMENA

- 3.5 Physical and Mechanical Effects..... 79
- 4. CORROSIVE ENVIRONMENTS
- 4.7 Molten Metals and Fused Compounds. 79

#### CHARACTERISTIC CORROSION PHENOMENA

#### 3.5 Physical and Mechanical Effects

3.5.3, 6.2.3, 6.2.4, 6.3.6, 3.7.4

Microfractographic Study of Cavitation Erosion in Metals. (In Russian.) V. V. Gavranek, D. N. Bol'shutkin and V. F. Zozulya, Fizika Metallov i Metallovedenie, 10, 84-89 (1960) July. Fractures of heat treated and quenched

chromium and carbon steels and alu-minum bronzes are studied by magnetostriction vibrates in water to determine cavitation erosion as a function of brittle fracture of the crystals which de-pends on declination surface and crystal orientation. Increased erosion resistance is achieved by adequate heat treatment or additional alloying. 7 references.—
RML. 21340

#### 3.5.5, 5.3.4, 2.3.4

The Nature, Cause, and Effect of the Porosity in Electrodeposits. Pt. V. An Evaluation of the Sensitivity of the Ferroxyl Test. Fielding Ogburn, D. W. Ernst and W. H. Roberts. Plating, 46, No. 9, 1952-1953 (1959).

The ferroxyl tests, modified to avoid attack of Ni by eliminating contact between ferricyanide and Ni, was used to determine the porosity of gold coatings on steel; the coatings were then stripped and the pores counted photographically. Pore size was measured with a filar microscope. < 50% of all pores present were detected by the ferroxyl test, the actual % increasing with pore size.— MA.

#### 3.5.4, 6.3.11, 3.2.3, 3.5.6

Effects of Gamma-Radiation on the Absorption of Hydrogen In Metals. (In Japanese.) Kazuka Yokogawa and Takesi Sugeno. J. Japan Inst. Metals (Nippon Kinzoku Gakkai-Si), 24, No. 2, 113-117 (1960).

The amount of hydrogen absorbed by palladium was determined by measuring patladium was determined by measuring the change in electrical resistance. No absorption was observed during irradiation even for a long time, when palladium wires were immersed in acid or alkaline solution. On the other hand, palladium with a chemically formed thin oxide film absorbed a large amount of bydragen in dilute culture social or in hydrogen in dilute sulfuric acid or in

dilute hydrochloric acid, and it is con-cluded that a thin oxide film is neces-ductors.-MA.

#### 3.5.9, 6.3.10, 4.7, 8.4.5

3.5.9, 6.3.10, 4.7, 8.4.5

High Temperature Corrosion Study
Interim Report for the Period November 1958 Through May 1959. C. F. Hale,
E. J. Barber, H. A. Bernhardt and Karl
E. Rapp. Oak Ridge Gaseous Duffusion
Plant. U. S. Atomic Energy Commission Pubn., AECD-4292, July 28, 1959
(Declassified October 22, 1959), 39 pp.
Available from Office of Technical Services, Washington, D. C.

This is a corrected version of an earlier report prepared as KL-498.

lier report prepared as KL-498.

Samples of grade A Monel and grade
A nickel were subjected statically in a
single reactor to an undiluted atmosphere gaseous fluorine at pressures up to one atmosphere absolute and temperatures up to 1500 F. The grade A Monel was conservatively estimated to have consumed at least 40 times as much fluorine as grade A nickel during the entire period of investigation. Samples of fused α-Al<sub>2</sub>O<sub>3</sub>, α-Al<sub>2</sub>O<sub>3</sub>-MgO spinel, and α-Al<sub>2</sub>O<sub>3</sub>-NiO-nickel cermet were exposed to undiluted fluorine at one atmosphere absolute pressure at temperatures of 1340 and 1500 F. Results indicated that the  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> is as good as the Ni in the region of 1300 F. Grade A nickel samples coated with nickel fluoride films of 37,000 and 74,000 A, respectively, were exposed to an absolute pressure of gaseous UF<sub>8</sub> of 12 cm of Hg at temperatures of 1000 and 1800 F.—NSA.

#### 3.5.9, 4.2.3, 4.7, 4.3.5, 3.2.2

Steels in High Temperature Service. Thomas W. Krebs. pp. 287-317 of Proc. Short Course on Process Industry Corrosion. Book, 1960, National Association of Corrosion Engineers, 1061 M & M Ruilding Houston 2, Toxon 2 Building, Houston 2, Texas.

One of 22 papers presented at the short course, Ohio State University, Sept. 12-16, 1960. General considerations involving the choice of materials for high temperature (over 400 F) service are given. Common causes of tubing failures are listed and discussed. Effects failures are listed and discussed. Effects of oxygen, repetitive stresses, design considerations, oil ash corrosion, molten metals, sulfur, hydrogen attack, nitro-gen, carbonaceous atmospheres, carburization, pitting, shut-downs, acid cleaning are reviewed. There is one table, 12 references and 17 figures, mostly of

Abstracts in This Section are selected from among those supplied to sub-scribers to the NACE Abstract Punch Card Service, Persons who are interested in reviewing all available abstracts should write to NACE for information on this service.

corroded specimens, but also diagrams showing the effect of various factors in the high temperature corrosion problem.

Fretting in the Light of Aircraft Experience. P. B. Walker. J. Roy. Aeronaut. Soc., 63, No. 581, 293-298 (1959). Fretting is a local disruptive process, caused by two surfaces rubbing together.

Loosely fitting bolts and nuts are examples. Walker directs attention to the lack of fundamental knowledge and con-flicting evidences. Fretting may cause or relieve fatigue.—MA. 20312

Stress Corrosion Cracking of Austenitic Stainless Steels in Varying Concentrations of Alkali and Earth-alkali Chlorides. (In English.) Stig Berg and Sture

Henrikson. Jernkontorets Annaler, 144, 392-396 (1960) May.
Samples of 18-8 steel are exposed to a tensile load of 15 kg/sq. mm. in an aqueous solution of LiCl, MgCl<sub>2</sub> or NaCl at 100 C. Effect of concentration on the time elapsing from the start of loading time elapsing from the start of loading to rupture. 3 references.—RML. 21128

#### 3.5.8. 3.2.2

Current Problems (In Stress-Corrosion Fracture) for Additional Consideration. L. R. Scharfstein. (Amer. Inst. Min. Met. Eng. Conf. on) Phys. Metallurgy of Stress-Corrosion Fracture, Pittsburgh 1959, 1959, 373-379.

An attempt to organize and interpret those aspects of the subjects of stress-corrosion fracture, which seem of im-

corrosion fracture which seem of importance for future consideration. From this viewpoint remarks are made on the mechanism for the initiation of cracking, theories of crack propagation, the wedging effect, three-dimensional factors in crack growth, hydrogen embrittlement and proton mobility, and the influence of alloy composition and of plastic deformation on crack susceptibility. 16 references .- MA.

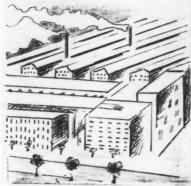
#### CORROSIVE ENVIRONMENTS

#### 4.7 Molten Metals and Fused Compounds

Corrosion of Refractories by Liquid Slags and Glasses. A. R. Cooper, Jr. and W. D. Kingery. pp. 85-92 of "Kinetics of High-Temperature Processes." W. D. Kingery, editor. Book, 1959, 342 pp. Massachusetts Institute of Technology, Cambridge, Mass. and John Wiley & Sons, Inc., New York, N. Y.

Corrosion mechanisms are affected by both physical and chemical properties of the refractory and the liquid slag or glass. Corrosion may take place by a solution process at the surface or by a penetration of liquid into solid grains, grain boundaries, or pores. The limitations concerning the evaluation of corrosion of refractories are discussed on an experimental basis. Sufficient infor-mation is available to support the con-

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clusion that the appropriate values for refractory-slag systems fall well out-side those generally encountered in con-vection heat-transfer or diffusion-transfer experiments. A comparison is made of a model system (NaCl, glycerine-water) with a high-temperature system (sapphire, CaO-Al<sub>2</sub>O<sub>2</sub>-SiO<sub>2</sub> slag) for the maximum and minimum values of the Grashof, Reynolds, and Schmidt Num-bers. It is shown that the dimensionless qualities of the model system completely encompass those of the actual system, affirming the suitability of the chosen model.—NSA. 20537

The Liquid Metal Corrosion Problems. (In Czech.) Alois Dvořák. Akimov. State Univ., Prague. Jaderná energie, 6, 155-162 (1960).

Recent research on the specific character of corrosion of construction materials by liquid metals as well as factors influencing the development of these corrosion processes are reported. The characteristic effects of corrosion by liquid metals, the principles of corrosion test methods, and the main methods of increasing the corrosion resistance of construction materials are given. (auth) -NSA.

4.7, 6.2.2

Corrosion of Iron in Molten Nitrates and Chlorides of Group I and II Metals of the Periodic Table. (In Russian.) V. P. Kochergin, E. P. Druzhinina, G. V. Men'shenina and E. P. Asanova. J. Applied Chem. (Zhur. Priklad. Khim.), 33, 1580-1586 (1960) July.

The corrosive behavior of iron in the The corrosive behavior of iron in the molten-salt mixtures of NaNO<sub>3</sub>-MgCl<sub>2</sub>, NaNO<sub>3</sub>-ZnCl<sub>2</sub>, NaNO<sub>3</sub>-LiCl, NaNO<sub>5</sub>-KCl, Ca(NO<sub>3</sub>)<sub>2</sub>-NaCl, Sr(NO<sub>3</sub>)<sub>2</sub>-NaCl, Ba(NO<sub>3</sub>)<sub>2</sub>-NaCl, and KNO<sub>3</sub>-NaCl was investigated in order to provide the necessary theoretical background for choosing suitable moltan-salt mixtures choosing suitable molten-salt mixtures for use as a flux, heat-transfer agent, or heat-treating medium. It was found that the corrosion rate increases with increasing chloride content of the melt, with the chloride ions playing the role of activator in the nitrate-chloride mix-tures. Removal of residual water at high vacuum at 400 C results in a lowering of the corrosion rate; however, an opposite behavior was observed in the Ca(NO2)2-NaCl mixtures. This is explained by the decomposition of the nitrate and the interaction of the iron with the chemically active nitrite, according to the equation 9Fe+4Ca(NO<sub>2</sub>)<sub>2</sub> 4CaO+3Fe<sub>3</sub>O<sub>4</sub>+4N<sub>2</sub>.—NSA. 214

4.7, 6.2.2

Dissolution of Iron in Melts Contain-Dissolution of Iron in Melts Containing Lithium Chloride and Sulphates of Alkali and Alkaline Earth Metals. V. P. Kochergin and N. Ye. Bogatyreva. Nauch. dokl. vyssh. shkoly. Khim. i khim. tekhnol., No. 1, 206-209 (1959). Translation available from Administrative Secretary, Pergamon Institute, 122 East 55th Street, New York 22, N. Y.; Headington Hill Hall, Oxford, England. The corrosion of Fe was studied in LiCl-Na<sub>2</sub>SO<sub>4</sub>, LiCl-K<sub>2</sub>SO<sub>4</sub>, LiCl-CaSO<sub>4</sub> and LiCl-MgSO<sub>4</sub> melts (M), used in heat-treatment at 700°. The effect of sulfates of different metals on the rate sulfates of different metals on the rate of dissolution of Fe was determined. It is concluded that the process of dissolution of Fe in the M studied is limited by the diffusion of the products of dissolution of Fe into M and the diffusion of oxidizing agents from M towards the

Fe surface. Raising the temperature in

the range of 550-750° increases the rate of dissolution of Fe, which may be ex-plained by the reduced stability of the sulfates examined at higher temperatures. Study of the effect of M composition on the rate of dissolution of Fe has led to the conclusion that O2 from the air does not readily dissolve in the molten salts and that increased solubility of metal in M is due to the presence in M of the products of high-temperature hydrolysis of the salts. To remove the traces of moisture, hydrolysis remove the traces of moisture, hydrolysis products etc. from M, in order to reduce the solubility of metal in M, high-temperature blowing of M with dry air is recommended. 12 references.—PI. 21381

4.7, 6.2.5, 3.2.2 Carburization of Austenitic Stainless Carburization of Austenitic Stainless Steel in Liquid Sodium. W. J. Anderson and G. V. Sneesby. Atomics Interna-tional, Div. of North American Avia-tion, Inc. U. S. Atomic Eenergy Com-mission Pubn., NAA-SR-5282, Sept. 1, 1960, 32 pp. Available from Office of Technical Services, Washington, D. C. Regults are presented of experimental

Results are presented of experimental Results are presented of experimental research concerned with carbon transfer in liquid sodium-304 stainless steel systems. The general nature of the reactions is discussed, and experimental techniques are described. The reaction rates in the liquid sodium system were found to be rapid, and carburization rates for the steel were governed by diffusion rates. The carbon content of 304 stainless steel in equilibrium with carbon-saturated sodium varies from carbon-saturated sodium varies from 2.68% at 1000 F to 4.35% at 1600 F. Sodium containing 15 to 18 ppm carbon is in virtual equilibrium with uncar-burized 304 stainless steel at 1200 F, when the oxygen concentration in the sodium is less than 40 ppm. Diffusion coefficients for carbon in 304 stainless steel are presented in the temperature range of 1000 F to 1600 F. A method of using micro-hardness data from carburized stainless steel specimens for burized stainless steel specimens for indirectly determining the carbon content of sodium is described. (auth)-NSA. 21119

4.7, 6.2.5, 6.2.3, 6.3.10

Study of Mass Transfer of Metal and Alloys in Liquid Bismuth-Lead Eutectic

Alloys in Liquid Bismuth-Lead Eutectic Alloy. (In Japanese.) Takeshi Akutagawa and Kiyoyuki Ogawa. J. Japan. Inst. Metals, 24, 256-260 (1960) April. Study of corrosion and mass-transfer of 18-8 stainless steel, mild steel, 5% Al-Fe, Croloy 5 Si, Monel and Ni in liquid Bi-Pb eutectic alloy by the thermal convection loop. Ni and Monel were completely mass-transferred. The corrosion loss was most remarkable in mild steel; in 18-8 stainless steel and 5% Al-Fe it was moderate and in 18-8 Mo stainless steel and Croloy 5 Si it was comparatively light.—RML. 20402

4.7, 6.2.5, 3.2.2, 3.7.4

Effects of Diffusion on Corrosion of Metals by Fused Salts. C. Edeleanu, J. G. Gibson and J. E. Meredith. J. Iron and Steel Inst., 196, Pt. 1, 59-61 (1960)

In equimolar NaCl, KCl, at 800 C it is almost invariably found that stainless steels form grain boundary voids. These are considered to be the result of in-ternal diffusion and selective oxidation of one or more of the components. Metallographic examination of the corroded alloys indicated in this instance that the selective removal of Cr was responsible for the formation of voids.— BTR. 21307

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October, 1961

No. 10

Topic of the Month

# Premature Failure of Copper-Nickel Alloys in Sea Water\*

By H. E. STOVER

#### Introduction

METHOD of extending the service life of creosoted wooden piles in marine borer infested sea water has been adopted in recent years by the Port of Los Angeles. The principle involves encapsulating the attacked section of a pile in place, thereby cutting off the oxygen supply to the marine borers causing the damage. Commercially available plastic film, (polyvinyl chloride, neoprene, etc.) 0.020 inch to 0.030 inch, was used for this purpose. In some cases, these plastics were banded to the piles with either Monel or 90/10 copper-nickel bands by a diver. Extensive tests at the Port of Los Angeles, and at Harbor Island, N. C., indicated that either of these alloys should be capable of holding the wraps in place. Corrosion rates of both alloys indicated long service life. Although copper-nickel was preferred, Monel was recommended as a second choice when copper-nickel was not readily available, and when fouling was not a problem.

The copper-nickel tag shown in Figure

Abstract

Abstract

Monel and 90/10 copper-nickel bands used to tie plastics around pilings failed after 1-year exposures in salt water. Normally a far greater service life is obtainable with these alloys in this environment. The corrosion seemed to be greatest near the mudine. It was found the black material on both metals was a mixture of sulfides and alloyed metals, and furthermore that both strips were somewhat magnetic. Several possible theories were advanced to explain these premature failures, none of which have been confirmed. Investigations continue.

1 was preweighed and measured, then used to identify a 6-inch x 12-inch concrete cylinder submerged in sea water in 1942. Almost eighteen years later, the tag and wire were removed, reweighed, measured, and the corrosion rate calculated. The rate was just slightly less than

0.7 mdd. The tag and the wire are still in very good condition and the numbers are quite legible. On this basis, it was assumed that copper-nickel or Monel would be the material to install and from which maximum service could be

Approximately one year after some of the first installations of this type were made in the outer harbor, a hard-hat diver, while making a routine submarine piling inspection,2 observed that some of the bands had suffered extreme corrosion. Both copper-nickel and Monel bands were involved. Some of the bands had fallen off the piles and were lying on the bottom. The corrosion seemed to be most severe near the mudline. A number of the samples were recovered, and



<sup>\*</sup> Assistant Testing Engineer, Port of Los Angeles, Engineering Division, Wilmington, Calif.

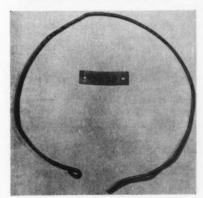


Figure 1—Copper-nickel tag and band after nearly 18 years exposure to sea water. The corrosion rate was slightly less than 0.7 mdd.

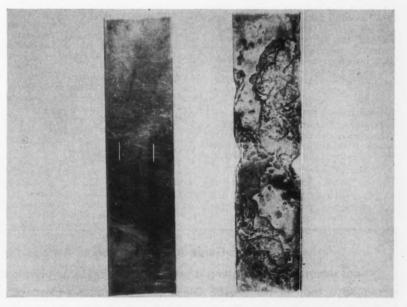


Figure 2—Three-quarter inch copper-nickel bands. The strip on the left was not exposed. The strip on the right was cut from a band that had failed after six months exposure to sea water. The corrosion rate of this particular section was about 50 mdd.

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analyzed. The black material on the Monel and copper-nickel bands was found to be a mixture of the sulfides and the alloyed metals. Furthermore, both the Monel and the copper-nickel strips were found to be somewhat magnetic whereas neither the tag nor wire shown in Figure 1 were magnetic.

The copper-nickel specimen at the right of Figure 2 had been exposed only six months, and suffered a corrosion of about 50 mdd.

A full-scale laboratory investigation is now under way in order to determine the cause of this premature corrosion

and how future failures of this type can be prevented. It is hoped the answers to the following questions will be forth-coming from this investigation.

- 1. How can metallic sulfide be formed on the surface of any metal in the presence of oxygen-bearing sea water?
- 2. Is there possible local action between the metals and the hydrogen sulfide produced by ocean bottom bacteria such as desulfovibrio?
- 3. Is the key to the whole situation due to the fact that in cold working of some of this material the magnetic prop-

erties imparted have made the bands susceptible to rapid attack?

- 4. Is it possible that in fastening bands themselves, the diver overstressed them and thereby made stress corrosion possible?
- 5. Could crevice corrosion play a prominent part in this problem?

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- 1. C. M. Wakeman and L. L. Whiteneck. Extending Service Life of Wood Piles in Sea Water. Symposium on Treated Wood of Marine Use, Spec. Tech. Pub. No. 275, ASTM, 1959.

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Any discussion of this article not published above will appear in December, 1961 issue.

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# **Galvanic Anodes and Fresh Water Rinse** Reduce Tanker Corrosion\*

By E. E. NELSON

#### Introduction

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FEW YEARS ago the outlook for improving tanker corrosion did not appear very bright. Only optimists expected that corrosion in tankers could be greatly reduced in the near future. In 1956 the literature reported tanker corrosion to be severe and costly.1 A commonly accepted figure was \$150,000 vearly for a T-2 tanker. It was reported that corrosion occurred in many different forms and appeared to be the result of many factors. However, today the out-look is much more favorable. This has been brought about through the collective efforts of many companies, individuals and industry committees. Recent mitigation techniques have been successful. Knowledge gained on the corrosion processes involved should be useful in solving the remaining problems.

The purpose of this paper is to discuss this transition period in tanker corrosion technology with the hope of stimulating additional thought and work in this field. This paper is based on inspections of more than a thousand cargo compartments during the past five years. Inspections covered progressive stages in the development of corrosion. Additional background has been obtained through discussions with many others in the industry, especially those active on American Petroleum Institute and National Association of Corrosion Engineers committees.

#### Causes of Corrosion

Although a number of other explanations have been suggested during industry committee meetings, practically all corrosion in tanks can be explained as galvanic corrosion of steel in sea water. Even heavy pitting in crude tankers can be shown to occur in accordance with this theory. While crude oils and heavy oil products can cover the surface of steel with an oily film that greatly reduces general corrosion, the oily film does not stop the cathodic reaction, which in sea water, is the reduction of dissolved oxygen to form hydroxyl ion. This situation is created where a large potential cathode exists similar to steel covered with either copper plate, mill scale, or rust. When relatively small breaks or weak spots in the oil film ex-pose bare steel to sea water, corrosion will be concentrated at these points and pits will form. For this to occur the water layer must cover a large enough area of cathode to accept the current from the bare steel anodes.

#### Abstract

Abstract

Based on inspection of more than a thousand tanker cargo compartments, types of corrosion are classified under four operating conditions. These are the presence or absence of ballast water and petroleum material cargoes of low or high viscosity. Pitting in crude tankers is explained as simple galvanic corrosion. Data and experience with successful cathodic protection systems using magnesium and zinc anodes are discussed. At present the zinc systems appear to be the more economical. Data are presented showing that appreciable hydrogen is generated by magnesium systems but not by zinc systems. The benefits of fresh water rinsing are indicated by test panel data and from inspections.

5.2.2, 8.9.5

As an example, to form a pit  $\frac{1}{2}$  inch in diameter and  $\frac{1}{4}$  inch deep in one year at a uniform rate requires a constant current of about 0.7 milliampere. This is sufficient current to polarize 0.2 sq ft or more of oil coated steel.

Pitting in crude oil tanks has also been explained by the action of acidic components in the crude oil and by bacterial corrosion. These are certainly possibilities, but they appear to be much less likely than the conditions for galvanic corrosion cited above.

Corrosion by "sour" or high sulfur crudes seems to be a general concern. There is reason for this concern in the refining of such crudes, but not during their shipment in tankers. Some crudes contain hydrogen sufide as they come from the wells, but generally this gas is removed by stripping with some other gas before shipment. The rest of the sulfur in the crude is combined and is not corrosive to steel under shipping conditions. This has been proved many times and is the consensus of tanker committee members from other oil companies.

Bacterial action can produce hydrogen sulfide from the combined sulfur in petroleum when sufficient nutrients are present to support bacterial growth. However, present tank cleaning methods usually wash out polluted water that could help support bacterial growth. After such washing the tank is not, of course, sterile but it also is not in a condition conducive to bacterial growth. Therefore, liberation of corrosive hydrogen sulfide as a result of bacterial action should not be significant.

Because pitting is very prevalent in crude tankers unless some corrosion preventive method is used, there seems to be a strong argument to rule out causes that probably would occur infrequently, such as acidity and bacteria. However, galvanic corrosion is an ever present possibility. In support of the simple galvanic corrosion theory is the fact that similar pitting often occurs in tanks that carry refined or clean products which are in no way associated with acidity or bacteria.

About the Author



E. E. NELSON, corrosion engineer at Socony Mobil Oil Company's Paulsboro, New Jersey Technical Service Laboratory. He formerly was with the Naval Research Laboratory for 11 years. He has been a member of NACE since 1954.

Rust scale in tankers represents a large potential cathode area, which can support pitting in clean products trade. First, in this process, the rust scale builds up to a thickness of 1/16 inch or more. Then rust blisters 1 to 3 inches in diameter may form because the compressive forces in the scale weaken the adhesion between the rust scale and the steel substrate. Often the covering breaks off the blisters, exposing bare steel which will corrode at a high rate. When the rust scale surrounding the bare steel remains intact, pitting of the bare steel occurs. Often, however, larger sections of the rust come off and general corrosion of the bare steel occurs once more.

It has been observed that pitting surrounded by rust scale, as described above, occurs more often with heavy, oily products than with light volatile products. Apparently, the oily materials help maintain the rust scale intact without interfering with the cathode reaction. Some pitting does occur in tanks that carry light products but usually the rust scale becomes detached and corrosion becomes general. It seems likely that oil films protect the rust scale from electrolytic descaling by the corrosion currents while the light products cannot give this protection. The reduction of rust is discussed in more detail later.

#### Summary of Tank Inspections

Based on visual inspections the characteristics of corrosion in tankers can be separated by certain important operating factors. These classifications are:

- 1. Tanks that seldom carry ballast,
- 2. Tanks that often carry ballast,
- 3. Tanks with cargoes of light products that do not leave a protective film, such as gasoline and solvents, and
- 4. Tanks carrying heavy petroleum materials that leave a protective film; examples are crudes, lubricating oil stocks and domestic fuels.

The lightest corrosion occurs in tanks that contain ballast infrequently and carry oily cargoes most of the time. Corrosion usually is negligible in tanks ballasted no more than 2-3 percent of the time and carrying oily cargoes at least

<sup>\*</sup>A paper presented under the title "Tanker Corrosion and the Use of Galvanic Anodes," at the 17th Annual Conference, National Asso-ciation of Corrosion Engineers, Buffalo, N. Y., March 13-17, 1961. Submitted for publication February 23, 1961.

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#### TABLE 1—Corrosion Test Panel Data Showing Effect of Cathodic Protection

		Panel Distance		Corrosion	Rate, mp	V
Tank No.	Magnesium Anode	Underdeck, Ft.	6 Mo.	12 Mo.	22 Mo.	34 Mo. (1)
2 Starboard	No 	2 2 21 21 41 41	5.8 8.6 5.2 6.2 5.8	10.7 6.8 5.9 5.9 6.2 6.2	10.0 9.5 4.0 4.1 3.9 4.0	
Average			6.3	6.9	5.9	
2 Port	Yes	2 2 7 7 21 21 28 28 41 41 41 41	7.5 5.3 6.6 4.0 4.4 3.0 3.7 4.6 3.9 4.5 3.4	7.1 7.1 5.2 5.9 3.1 2.6 2.8 2.6 3.1 3.9 3.3	6.9 1.6 6.1 2.5 2.6 1.7 1.8 2.1 2.4 1.9	
Average			4.6	4.2	2.9	
5 Port	No	2 2 21 21 41 41	6.7 6.7  7.9 6.6	10.1 11.7 6.8 6.0 6.9 6.7	9.6 4.7 4.6 4.8 4.3 4.5	7.2 6.9 4.5 4.2 3.1 3.8
Average			7.0	8.0	5.4	5.0
5 Starboard	Yes	2 7 7 7 21 21 28 28 41 41 41	7.5 5.3 6.6 4.0 4.4 3.7 4.6 3.9 4.5 3.4	4.9 5.6 8.1 8.5 2.7 2.7 2.4 3.5 3.4 2.6 1.8	6.8 6.0 4.0 2.7 2.0 1.9 2.2 2.4 1.2 1.3 2.0 1.8	5.8 3.4 3.2 1.9 0.5 2.2 1.8 1.2 1.4
Average			4.6	4.1	2.9	1.9
8 Starboard	No  	2 2 21 21 41 41	4.9 4.3 5.0 4.9 4.6 4.0	7.0 5.5 6.2 5.5 5.1 6.2	4.5 4.6 4.1 4.5 4.3 4.6	4.7 3.3 3.4 3.4 3.4 3.4
Average			4.6	. 5.9	4.4	3.6
8 Port	Ves	2 2 7 7 21 21 28 28 41 41 41	4.5 3.4 3.0 4.5 2.6 3.4 2.9 3.2 4.7 4.7 4.7 3.8 3.8	3.2 3.4 3.0 3.1 3.0 2.6 3.6 3.3 3.4 3.6	2.2 2.9 2.4 3.1 2.0 0.6 3.4 1.8 1.9 2.1 2.3	2.1 1.8 2.1 1.6 1.4 1.5 1.5 1.5
Average			3.8	3.2	2.3	1.8

(1) Anodes were removed from this tank after the 22-month period.

50 percent of the time. With more ballast time and with most of the cargoes of an oily nature, the chief change in corrosion is the development of pits on horizontal surfaces that face upward such as tank bottoms and top surfaces of structural members. Horizontal surfaces facing downward and vertical surfaces in such service almost never suffer pitting and usually general corrosion is light. The amount of pitting and the length of time for pitting to become significant seems to be directly related to the amount of ballast time.

Tanks that carry light cargoes, such as gasoline and solvent, may suffer general corrosion at more than twice the rate of tanks carrying heavy oil. In non-ballast tanks, the corrosion is due to moist air. The corroding metal develops a thick rust scale that continues to develop for several years. Eventually the compressive

forces in the scale become greater than the adhesive forces<sup>2</sup> and the rust comes off in large, thick sheets.

In ballast tanks with light cargoes, thick rust scale also develops, but usually shedding starts sooner than in non-ballast tanks; also, the scale is softer and comes off in smaller sections. This seems to be due to "autoreduction," hich is iron acting as an anode producing a cathodic reaction consisting of the reduction of ferric oxide. This reduction of ferric oxide undermines the rust scale. The process is similar to that of electrolytic descaling. When blisters form in the rust and break open, as was discussed above, pits may develop in clean product tanks that are ballasted. The severity of pitting will depend on the relative size of the bare areas to the rust covered areas and the length of time the relationship continues. If after a short time, larger areas of scale fall off, pitting will decrease and general corrosion will occur.

#### Use of Galvanic Anodes

Galvanic anodes have been one of the most successful and economical corrosion preventive methods for ballast tanks that have been tried so far. Before anodes were used in tanks, it had been established that cathodic protection could successfully reduce corrosion on many structures permanently submerged in sea water. However, a serious doubt arose on the use of cathodic protection in ballast tanks because the tanks usually contain water only about 25-35 percent of the time. It was speculated that even 100 percent protection during ballast time might reduce corrosion by only a small fraction. Also, it was wondered if cathodic protection could be established in ballast periods of 4-5 days without requiring the use of such a large number of anodes as to be uneconomical.

#### Use of Magnesium Anodes

With the above question in mind, several tests using magnesium anodes were started about a decade ago. Successful results from some of the tests led to more extensive installations until today cathodic protection in ballast tanks is standard practice in many tanker fleets. Some typical operating conditions are discussed below.

Concerning the amount of ballast time, work by Blatchford and Norris<sup>7</sup> showed that 15 percent of the total time in ballast was insufficient for cathodic protection and that 20 percent resulted in sufficient corrosion reduction to balance the cost of the anode installation. The writer has experience with several ships where 25 percent ballast time gave good results for cathodic protection. Other tanks with 35 percent ballast time have had even less corrosion.

Corrosion test panel results from a typical ship carrying mixed clean cargo between the Gulf and the East Coast of U. S. are given in Table 1. Tanks No. 2 Port, No. 5 Starboard and No. 8 Port contained magnesium anodes while No. 2 Starboard, No. 5 Port and No. 8 Starboard did not. The anode installation was similar to the example presented later in this article.

Considering Table 1, it should be understood that the port and starboard compartments of the same tank always carried the same cargo on any given trip. This was not true for different tanks, however. No. 2 Tank carried more cargoes of gasoline than the other tanks under test, while No. 8 Tank carried more domestic fuel oil and other heavier products. No. 5 Tank fell in between the other two with more nearly equal numbers of cargoes of gasoline and of fuel oil. Another consideration to keep in mind is that all of the tanks were rinsed with fresh water whenever possible after either sea water ballast or tank washing. It is believed that this practice accounts for the general low corrosion rates that occurred even in the control tanks. Therefore, effects of cathodic protection can best be studied by comparing port and starboard compartments of the same

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# TABLE 2—Test Panel Corrosion Rates for Successive Periods with Cathodic Protection of Ballast Tanks

	D-11	36.4	rage Corro	osion Rate, mpy					
Tank No.	Ballast Time, %	Magnesium Anodes	0-6 Mo.	6-12 Mo.	12-22 Mo.	22-34 Mo.			
2 Starboard	32 32	No Yes	6.3 4.6 25	7.6 3.8 50	4.7 2.2 53				
5 Port	33 33	No Yes	7.0 4.6 34	9.0 3.6 60	2.3 1.4 39	4.3 0.5 88			
8 Starboard 8 Port. Corrosion Reduction, Percent	33 33	No Yes	4.6 3.8 17	5.2 2.6 50	3.8 1.2 68	2.1 0.9 57			

#### Reduction of Corrosion Shown

Table 1 clearly shows a reduction in corrosion due to the action of the magnesium anodes. Also the amount of reduction increases with increased age of the installation. In all tanks the lowest corrosion rates occurred on the panels nearest the bottom. In the tanks with anodes, the reduction in corrosion was considerable for panels 7 ft or more under the deck. Some protection was experienced on panels 2 ft below deck, but corrosion reduction was less than would be desirable. The panels 2 ft and 7 ft below the deck are about equally close to anodes.

Since the tanks are completely filled with ballast, even up into the tank trunks, it was unexpected that these panels would corrode differently. The following two conditions may explain this difference. First, the 2 ft level panels are much nearer the underdeck which has no anodes and, therefore, these panels receive a lower current density. Second, cargo levels were usually just below the panels at 2 ft and during this period these panels are exposed to moist air. At the 7 ft level panels generally were covered with cargo. Whatever the explanation may be, the data indicate that some better protection of underdeck areas is desirable.

In Table 1 the corrosion rates are average for the total exposure time. The progressive effects of cathodic protection can be shown more clearly by corrosion rates for each successive period in Table 2 which was calculated from the data in Table 1. To obtain Table 2, the average metal loss that occurred in the first 6 months was subtracted from the average metal loss that occurred in the first 12 months. From this, the corrosion rate for the 6-12 month period was determined. The other data were calculated in a similar fashion. Both the corrosion rates and the corrosion reduction show improvement in successive periods.

Approximate extrapolations of the data in Table 2 were made to indicate the amount of steel loss to be expected after 10 and 20 years, respectively. The calculated results are in Table 3. Such data indicate whether or not cathodic protection can insure a 20-year life without steel replacement. Also, if the ship is expected to be obsolete after 20 years, it might be more economical to protect some of the ballast tanks (for example No. 8 Port) for only part of this time.

Effect of Anode Distance Evaluated

When test panels reported in Table 1 were installed, an attempt was made to locate them so as to measure the effect of distance from the anodes on the corrosion rate. The shortest panel-to-anode distance was about 2 ft. The distance between other panels and the nearest anode ranged from this distance up to 8 ft.

Analysis of the test panel corrosion rates showed no significant differences related to distance in this range. The panel data were supported by visual inspection which showed that current distribution was reasonably uniform. This result probably could have been expected because a panel close to a certain anode was at the maximum distance from other anodes, while a panel remote from an anode was equidistant from two or more anodes.

One benefit from protective anodes not shown by the panels, but clearly seen at the tank inspections, was a reduction in pitting corrosion. Numerous shallow pits were found in all control tanks. Pitting occurred where small areas of rust scale had come off, leaving bare steel exposed. From experience, it is expected that these pits will increase in depth with continued ballast. In contrast, there was no pitting in tanks with anodes.

#### Details of Anode System

Some details of a typical magnesium anode system used with good results in clean, coast trade are given below. In this ship the wing tanks were approximately 20 ft wide, 40 ft long and 44 ft deep. The center tanks were 40 ft wide, 40 ft long and 44 ft deep. Estimated total areas, including all structural members, were 14,000 sq ft for the wing tanks and 16,000 sq ft for the center tanks.

The anodes weighed about 50 lb each and were 16 x 7 x 7 inches in dimensions. Sixty anodes were installed in each wing tank. These were evenly distributed over the bottom, the side hull plate, the longitudinal bulkhead and the aft transverse bulkhead. No anodes were placed on the forward bulkhead or under the deck. In the center tank, 68 anodes were distributed over the bottom, on the aft bulkhead and on special supports about 15 ft under the deck.

The life of the anodes was three years with a ballast time of 25-30 percent. From the weight loss of the anodes and using an efficiency of 50 percent it was estimated that the average current density

TABLE 3—Cumulative Metal Loss Expected in Tanks Containing Magnesium Anodes

	<b>Expected Metal</b>	Loss, milli inch
Tank No.	After 10 Years	After 20 Years
2 Port 5 Starboard 8 Port	38 13 12	60 23 22

during ballast periods was 10 ma per sq ft. The system cost about \$1,900 a year total for a center tank and two wing tanks. The cost includes the price of anodes, installation and replacements, but does not include service charges on capital.

#### Painted Supports Economical

Some improvement in the economy of magnesium anodes should result, with painted steel supports. Studies on current distribution from anodes8-10 show that about half of the current from a magnesium anode will go to the bare steel sup-port of a typical tanker installation. If the supports are painted, current to the tank structure increases only slightly. Therefore, the life of the anodes would be substantially increased, perhaps as much as doubled. An estimate10 indicates that the indicated cost of \$1,900 for a complete tank could be reduced to \$1,400 per year by painting the anode supports. A coal tar-epoxy paint has been used to coat anode supports and is still giving good service after three years.

Some manufacturers have supplied

Some manufacturers have supplied magnesium anodes with galvanized steel cores in order to reduce wastage of current to the cores. Desirability of this practice is shown by the polarization curves of bare steel and galvanized steel in sea water, Figure 1. From these curves, it can be seen that magnesium, with a potential of 1.53 volts (Ag, AgCl), will deliver much less current to a galvanized surface than to a bare steel surface. It has been proved that with galvanized cores, there is less undercutting of the magnesium than there is with bare steel

While galvanizing has been helpful as a current shield on anode cores, it has a rather limited life. Because zinc is amphoteric, it is attached by the alkali formed by the cathodic current and is slowly dissolved from the cathode surface.

#### Use of Zinc Anodes

When improved zinc alloys<sup>11-13</sup> for use as anodes were reported, it seemed desirable to test them for protecting ballast tanks. One pound of zinc costing about \$0.20, develops about 350 ampere/hours of useful current. A pound of magnesium costs about \$0.45 and develops about 550 ampere/hours. These data give zinc a rating of 1750 ampere/hours per dollar versus 1220 for magnesium. Thus, zinc systems might provide cathodic protection at a lower cost than do magnesium.

Because zinc has a lower driving potential toward steel than does magnesium, it often has been considered to be at a disadvantage. For example, magnesium has four times as large a driving

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potential toward steel polarized to 0.90 volts (Ag, AgCl) as does zinc. For anodes of equal physical dimensions, four times as many zinc anodes would be required to furnish the same amount of current as would be supplied by a magnesium system. Because the density of zinc is 2.5 times that of magnesium, the weight of such a zinc system would be 10 times as great. Not only would this large weight be unacceptable but it would be very uneconomical to invest so much additional capital:

However, all of the disadvantages of low driving potential can be overcome by the use of long anodes with small cross sections. For a given weight of anode material, the greater the length, the more current it will produce. only limits are the practical considerations of casting the anodes and of supporting them when in use. The subject of anode design is treated in a paper by Shepard and Graeser.14

Details of Zinc Anode System

The size of the zinc anodes selected for testing in ballast tanks was 48 x 1.4 x 1.4 inches, each of which weighed about 27 lb. In laboratory tests, four of these anodes delivered as much current to a steel cathode at 0.90 volts (Ag, AgCl) as did one 50 lb magnesium anode, so, in designing the zinc anode system, this same ratio of 4 to 1 was used. For tanks similar to the example given above in clean products trade, 752 zinc anodes were used where 198 magnesium would have been required. On two ships with zinc anodes, inspections at six months and twelve months showed protection was equal to that from a magnesium system in every respect. Data from corrosion test panels and permanently mounted Ag-AgCl reference electrode led to the same conclusions. Several of the anodes were cleaned and weighed at each inspection. The weight losses indicate a five-year life for the anodes. Using this anode life and a cost of \$0.20 per lb for the anodes and \$4.40 each for installation, the average cost per year for a complete tank is estimated to be \$1500.

It should be mentioned that both magnesium and zinc seem very effective in protecting ballast tanks in crude carrying trade. In the cargo-ballast tanks fewer anodes suffice and usually these are mounted on bottoms of tanks only.

The danger of an explosion from sparks caused by falling chunks of magnesium has been covered by Baily,15 Titman and Wynn, <sup>16</sup> Margerson, Robinson and Wilkins, <sup>17</sup> Titman <sup>18</sup> and Grice. <sup>19</sup> These studies show that magnesium under certain conditions can produce a spark hot enough to ignite explosive gases. Aluminum was also able to cause ignition but was a much smaller risk. Zinc, however, has been found to exhibit no sparking tendency. If everything else is equal, this would represent an advantage for zinc.

#### Hydrogen Evolution in Ballast Tanks

Magnesium anodes are known to produce free hydrogen gas from water. To keep this hazard to a minimum, it is considered good practice to ballast anode

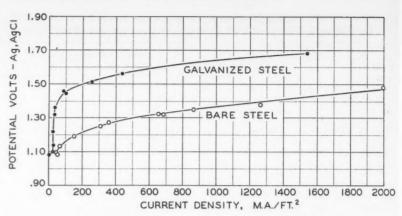


Figure 1-Polarization curves for steel and galvanized steel. (Unstirred sea water).

#### TABLE 4—Vapor Tests on Ballast Tanks Containing Zinc Anodes

		Percent of Lower	Explosive Limit			
	No. 2 Port T	ank No Anodes	No. 2 Starboard	Tank Zinc Anodes		
Hours After Closing Tank	Total Explosive Vapors	Hydrogen (Non-Absorbable)	Total Explosive Vapors	Hydrogen (Non-Absorbable)		
16	50 50 63 80	0 0.5 1.0 1.0	100+ 100+ 100+ 100+	0 0.5 1.0 1.5		
50	95 100 + 100 + 100 + 100 +	2.0 2.5 3.0 3.5 3.0	100+ 100+ 100+ 95 95	2.0 2.0 2.5 2.5 2.5 2.5		

TABLE 5-Vapor Test on Ballast Tanks Containing Magnesium Anodes

		Percent of Lowe	r Explosive Limit				
-	No. 2 Starboard	I Tank No Anodes	No. 2 Port Tank Magnesium Anode				
Hours After	Total Explosive	Hydrogen	Total Explosive	Hydrogen			
Closing Tank	Vapors	(Non-Absorbable)	Vapors	(Non-Absorbable)			
14	100+	0	100 +	50			
	100	15	100 +	45			
	100	0	100 +	100+			
	45	0	100 +	100+			

tanks completely full so that no large volumes of air and hydrogen can accumulate. Magnesium anodes usually would not be used to protect bottoms of tanks that must be filled only partially with ballast or with water from tank washings.

The volume of hydrogen liberated by magnesium anodes is equivalent roughly to useful current. Using a current density of 10 ma per sq ft and tanks of the size given above this would be 4.1 cu ft per hour.

Figure 1 shows that a much more negative potential is required for a given amount of current on a galvanized surface than on a bare steel surface. Because the reaction on both surfaces is decomposition of water and liberation of hydrogen, the curves indicate that zinc has a high hydrogen overvoltage. From this fact, it would be expected that very little hydrogen would be liberated on zinc anodes due to local action. The tests described below were conducted to investigate this situation for zinc and magnesium systems.

Hydrogen Evolution Tests Made

The tests were performed on two ships; one contained magnesium anodes and the other zinc anodes in most ballast tanks. On each there was at least one control ballast tank with no anodes. Both ships carried clean products in U. S. coastal trade. For the purpose of these tests only, the tanks were filled with ballast to a level about 1 ft below deck. The tanks had the same dimensions as the example above, so there was a vapor space of roughly 800 cu ft in the wing tanks and 1600 in the center tanks. The tank tops were secured soon after the ballast level was reached and the only vent was through a 2 lb pressure valve. The vapor was sampled through a stopcock fitting in the tank covers.

At each sampling time, readings were taken on two different meters. These were the Mines Safety Appliance Explosi-meter Model-2 and the Davis Vaportester Model M-6 Type L. The MSA meter gave readings about 25 percent . 17

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TABLE 6—Reduction of Corrosion Rates of Test Panels Due to Fresh Water Rinse

Date Removed	May 1959	May 1960
Months Exposed	13	25
Port Tank Fresh Water Rinse Corrosion Rate, mpy	No	Partial
Top Bottom	5.4, 4.9 4.6, 4.5	2.9, 2.6 2.8, 2.9
Starboard Tank Fresh Water Rinse Corrosion Rate, mpy	Yes	Yes
Top Bottom	2.9, 2.9 2.9, 2.9	1.6, 1.7 3.0, 3.0

lower than the Davis meter with this difference being consistent throughout the full range measured. For this test either of the meters was considered to be sufficiently accurate. Readings from both meters were given in percent of the lower explosive limit.

Procedure was the same with either instrument. First, the meter was connected to the tank through a rubber tube and the total explosive vapors were read. Then a fresh charcoal absorber was introduced in the sampling line and a second reading was made. The second reading indicated the presence of any non-absorbable gases such as hydrogen, methane, ethane or propane. Usually very little of the last three would be expected. A more positive indication of hydrogen would result from comparing the anode tanks with the control tanks.

Representative readings from the Davis meter are given as percentages of the lower explosive limits in Tables 4 and 5. Beside the tanks reported, vapor readings were taken on seven additional ballast tanks containing zinc anodes, five other containing magnesium anodes and two more control tanks. These additional data were very similar to the results reported.

At least three important conclusions can be reached from these data. The vapor space in most of the tanks carrying ballast contained sufficient petroleum vapors to produce an explosive atmosphere. In addition, enough hydrogen was liberated by the magnesium anodes to bring the vapor space into the explosive range. No significant amount of hydrogen was liberated by the zinc anodes. It would seem to be a matter of interpretation as to whether the hydrogen from the magnesium anode increased the hazard of a tank that already contained petroleum vapors. On the other hand, it can be stated that zinc introduced no additional hazard. On this basis, zinc anodes could be recommended to protect bottoms of tanks that are partially filled with ballast water.

Some of the measurements showed a small amount of non-absorbable combustible gases in the control tanks. This gas is presumed to be hydrogen formed by the corrosion process. Using the formula by Stern<sup>20</sup>, the amount of electrical current for the liberation of hydrogen from water at the pH of 8 is 6.1 x 10-2 ma/ft sq. In two days, considering that the wing tank area is 14,000 sq ft, about 0.8 cu ft of hydrogen would be expected. In the vapor space this would be 0.1 percent. This compares with the 50hour reading in Table 4 of 2 percent of the lower explosive limit (4 percent for hydrogen) or 0.08 percent in the control

There is a possibility that the reading in the control tank might result from low molecular weight hydrocarbons which also would not be absorbed by charcoal. However, when the meters were checked with gasoline vapors in the laboratory, all readings with the charcoal filter were zero. Considering this evidence and the calculation above, the gas is presumed to be hydrogen.

#### Use of Aluminum

The writer's experience with aluminum has been limited to tests with a few anodes and does not include any full scale installations. From reports by other investigators, however, there seems to be little doubt that aluminum can protect ballast tanks. At present the chief question is whether aluminum can do the job as economically as zinc and magnesium. As was stated above, zinc and magnesium furnish 1750 and 1220 ampere-hours per dollar, respectively at current market price. Aluminum anodes have been offered at \$0.35 per lb. Theo-retically, one pound of aluminum is equivalent to 1352 ampere-hours, but some indefinite portion of this is used to liberate hydrogen on the anode and is not useful current. To equal zinc on a dollar basis, aluminum anodes should have an efficiency of 45 percent. They would compare economically with magnesium if their efficiency were 32 percent. It is believed that more exact knowledge of the efficiency of aluminum anodes is needed before aluminum can compete economically.

#### Fresh Water Tank Rinse

So far the benefits of anodes have been discussed for ballast tanks only, because direct action of cathodic protection occurs in these tanks. However, there may be an important indirect benefit for nonballastic tanks. By ballasting the anode tanks as much as possible, the time other tanks are ballasted can be reduced substantially. Experience has shown that as the marine personnel become more familiar with cathodic protection and understand its function, the scheduling of ballast improves.

Another important corrosion preventive method is improved tank cleaning methods. Some years ago most operators stopped using hot sea water for most tank cleaning and found that cold sea water was satisfactory. More recently, rinsing with fresh water after either salt water ballasting or washing has appeared to be very helpful in reducing corrosion. The amount of fresh water is rather limited, of course, but on a tanker of about 30,000 D.W.T., most of the tanks can be rinsed for 20 minutes each with a total of 250 tons of water.

During recent years, there has been considerable decrease in corrosion as estimated by visual inspections and from test panel data. On tankers using these cleaning methods, corrosion rates of test

panels generally range from 3 to 7 mpy

with perhaps rates of about 10 mpy underdeck in a few tanks. Rates about twice as high would have been considered normal 10 years ago<sup>1</sup>. Much of this decrease is believed to be due to the present cleaning methods.

A test started in 1957 to develop some quantitative data on fresh water rinsing is described below. The test consisted of a fresh water rinse in a starboard tank after any exposure to sea water while the port tank was not rinsed. To aid in the evaluating, steel test panels were in-stalled in these tanks in April 1958. Panels were removed in May of 1959 and 1960. The corrosion rates are shown in Table 6.

Data for 1959 clearly show less corrosion as a result of the fresh water rinse. The reduction was 42 percent in the top and 37 percent in the bottom of the starboard tank. There is much less real distinction in 1960. The corrosion rate in the port tank had decreased materially and considering the accuracy of the data, is almost as low as in the starboard tank. This is explained by the tank utilization records which show that both tanks were subjected equally to fresh water washing over the last year. While this unintentionally changed the test, the reduction in rate in the port tank in 1960 indicates the effectiveness of fresh water rinsing.

#### Summary

Arguments are presented to show that most all corrosion in cargo compartments of tankers can be explained as simple galvanic corrosion. Successful installations of magnesium and zinc are discussed and representative costs indicated that zinc is the more economical of the two. The economic relationship with aluminum is briefly mentioned also. Data are presented showing that a significant amount of hydrogen is liberated by magnesium anodes but negligible amounts by zinc anodes. Data and inspections show that improved tank cleaning and fresh water rinsing is helpful in reducing corrosion.

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Editor's Note: See also "Symposium on Control of Internal Corrosion of Tankers." Corrosion, 9, No. 11, 387-424 (1953) Nov.

#### DISCUSSION

#### Question by Walter L. Miller, New York Naval Shipyard, Brooklyn:

The author's figures for costs of both magnesium and zinc anode systems appear somewhat low and are apparently the result of lower than usual labor costs for anode installations. However, I am

in full agreement with the anode requirements cited and also the estimated reduction in cost of a magnesium anode system by 'coating the anode supports. This partially confirms the economy disclosed in my paper "A Novel Cathodic Protection System for Tanker Ships" which was presented in the 1960 Marine Corrosion Symposium. In the described system the savings were sufficient to provide a coating for full protection of the bottom and practical elimination of sparking hazards at a cost of approximately 2/3 that of a conventional magnesium anode system over a ten year

Mr. Nelson is to be congratulated for his excellent presentation, especially with respect to details on proper use for zinc

#### Author's Reply:

The cost for magnesium anode systems, as reported in the paper, has been fairly reproducible at several shipyards and over several years. The cost of zinc installation has varied more. The figure of \$4.40 was from the first installation. The cost for a very recent installation was \$11.00 per anode. This increased the cost per year for two wings tanks, and a center tank to \$2000, which is slightly more expensive than the magnesium system (\$1900) reported in the paper. It is the author's belief that the anodes might be located so that the existing ship structure could be used instead of staging during the installation which should lower costs. Also Mr. Miller's proposed system of bottom painting and bottom anodes should be given consideration.

#### Question by W. S. Quimby, Beacon N.Y.:

Does the reference to fresh water rinsing include such rinsing of black or crude oil tanks used for ballast?

#### Author's Reply:

It is the author's opinion that fresh water rinsing would be helpful in crude tanker service. This is based on general information only and not on detailed experience. For example, in a laboratory test with artificial pits, the corrosion rate of the pits decreased six fold when the electrolyte was changed from sea water to tap. The data shown in Table 6 of the original is for a tank which carried No. 2 fuel oil (domestic fuel oil) for over 2/3 of the cargoes. The rest were light products such as gasoline. There is at least one conflicting thought on this subject, however. The mechanism of corrosion as discussed in the paper indicates that pitting is very importantly related to the amount of sea water ballast time. If this is a true relationship, fresh water rinse after ballast might not reduce the pitting directly. Indirectly, by rinsing the sea water from the tank, a more resistant film might be formed on the pit surface between ballast periods. However, aside from such consideration, at least the experience with No. 2 fuel oil encourages the belief that rinsing would help reduce corrosion in crude tankers.

Any discussion of this article not published above will appear in December, 1961 issue.

# Corrosion Problems Encountered In a Nickel Refinery Ammonia Absorption System\*

By R. B. McINTOSH

#### Introduction

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RELATIVELY simple process of absorbing ammonia from exhaust gases in the nickel refinery operated by Sherritt Gordon Mines has given some difficulty during several years of operation. During the early years entrainment in the gas and cooling water corrosion were problems. Later on carbon dioxide became a problem when the gas was used in the leach circuit. A corrosion theory is proposed to explain the resulting corrosion problem.

#### General Description of Process

The Sherritt Gordon process for treatment of nickel concentrates produced at the mine in Manitoba has been described in several papers. 1, 2, 3, 4 A simplified block flowsheet is shown in Figure 1.

The sulfide concentrates produced by conventional flotation techniques from the ore at the mine contain approximately 12 percent nickel, 0.5 percent cobalt, 1.5 percent copper, 30 percent iron and 28 percent sulfur. This finely water divided material is repulped in an am- AIR monia solution and pumped to leaching autoclaves. Under conditions of elevated temperature and pressure, oxygen supplied from a continuous flow of compressed air reacts with the sulfide minerals to produce a solution of ammonium sulfate containing the metals as complex amine salts. The tailings, consisting primarily of hydrated ferric oxide, are separated from the pregnant solution by a series of thickeners and filters. In the ammonia recovery circuit, ammonia is recovered from the spent leach gases as aqueous solution in a bubble-cap absorption column and recycled to the leach circuit.

Ammonia in the leach solution in excess of that required for subsequent operations is removed by distillation and is also recycled to the leaching circuit. The solution is purified by removing the copper, oxidizing the unsaturated sulfur compounds and hydrolyzing the sulfa-

The nickel is precipitated from the Habba purified solution by reduction with hydrogen under pressure. After reduction, the small amount of residual nickel and most of the cobalt are precipitated as sulfides with hydrogen sulfide and releached in a dilute sulfuric acid solution which is treated to separate nickel and cobalt and produce cobalt powder. The metal-free solution containing only ammonium sulfate is treated in triple-effect evaporators to produce ammonium sulfate fertilizer and condensate which is

About the Author

R. B. McINTOSH has been associated with Sherritt Gordon Mines, Fr. Saskatchewan, Alberta, since 1950 as a pilot plant opera-tor, maintenance engineer and finally as Head, Materials Engineering. He was grad-uated from the University of British Colum-bia and is a member of ASM and NACE.

#### Abstract

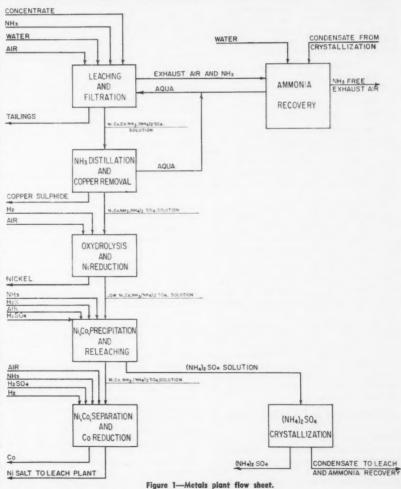
Abstract

Corrosion problems were encountered in a nickel refinery ammonia recovery circuit resulting from entrainment and carbon dioxide in leach gases. Techniques used to evaluate these problems are discussed. It was found that slurry was picked up by the gas leaving the autoclave and was not completely removed by the cyclone. As the gas passed through the cooler, its temperature was lowered and some ammonia and water vapor were condensed. This decreased the gas velocity sufficiently that near the cooler outlet some solids could settle out and be caught on tube wall imperfections. Deposition of such solids created ideal conditions for corrosion attack. Corrosive cooling water was also a factor.

A demister was installed in the gas line between the cyclone and cooler in an effort to reduce gas side corrosion. Greater effort was made to remove scale, and inhibitors were added to the water in an effort to build up a protective coating on tubes.

Special corrosion problems found in the scrubber, on the absorption tower, and on the cyclone are discussed in detail. Protective coatings were found helpful in reducing this type of carbon dioxide corrosion.

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<sup>★</sup> Submitted for publication March 28, 1961. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, N. Y., March 13-17, 1961.

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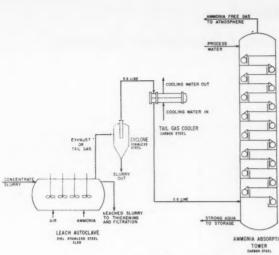


Figure 2-Original ammonia absorption system.

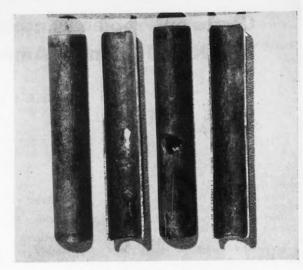


Figure 3—Tubes from lower half of gas cooler.

recycled to the ammonia recovery circuit and other parts of the leaching process.

#### Original Ammonia Absorption System

From the fall of 1954 when operation was started, until the spring of 1956 when changes were made, the equipment in the ammonia absorption circuit was as shown in Figure 2. Exhaust gases from the adjustment leach autoclaves had the following approximate analyses:

#### Percent by Volume

Nitrogen	×	×		,	*	è			73.1
Oxygen .									9.8
Ammonia									9.4
Water var									78

These gases at approximately 175 F were carried in a stainless steel pipe line to a stainless steel cyclone designed to remove any entrained solids carried with the gas. The remaining equipment and pipe lines were constructed from carbon steel.

The cooler was a two-pass type on both sides with gas on the inside and water on the outside of the tubes. It had a removable tube bundle which originally contained 11/4 inch, 14 gauge tubes. The absorption tower which was 6 ft. in diameter by 28 ft. high contained 16 trays with 63 bubble caps on each tray. Process water was pumped into the tower above the top tray and cooled gas at 90 F entered below the bottom trav. As the aqua descended by gravity from tray to tray, it was cooled by flowing over cooling tubes in each downcomer. These tubes were 3/4-inch diameter and were rolled into fixed tube sheets welded to the tower. Aqua discharged from the bottom of the tower contained about 18 percent ammonia.

#### Entrainment and Cooling Water Corrosion

#### Cooler

In 1955, a few months after the plant went into production, several tubes were found to be leaking in the bottom half of the cooler. In addition, severe pitting up to 0.040 inch was noted on the outside of tubes in the upper half. The lower half of the bundle was retubed in January and the upper half in February.

Some of the failed tubes were cut for visual and metallographic examination and scale was collected from both sides of tubes for chemical analyses. A photograph of two tubes from the lower half of the bundle is shown in Figure 3.

Visual examination revealed that these tubes failed from attack on both the inside and outside. Point of failure was about 2 feet from the gas outlet end where heavy, patchy internal scale was occasionally noted. Large areas of corrosion, as shown on the left hand tube were associated with this scale. A limited chemical analysis of the scale gave the following results: Ni — 3.74 percent, Co—.84 percent, Fe—50.0 percent, S—9.4 percent which indicated that the scale contained some slurry from the autoclause.

From visual and analytical information a theory was developed for the lower tube failures. Slurry was picked up by the gas leaving the autoclave and was not completely removed by the cyclone. As the gas passed through the cooler, its temperature was lowered and some ammonia and water vapor were condensed, thus decreasing the gas velocity sufficiently that near the cooler outlet some solids could settle out and be caught on any slight imperfections on the tube wall. Deposition of these solids created ideal conditions for corrosion attack on the tube wall. The familiar oxygen and solution concentration cell attack was probably enhanced by the formation of reducing compounds such as S2O3=, S<sub>4</sub>O<sub>6</sub>=, and H<sub>2</sub>S under the sulfide type deposits. In addition to causing corrosion attack, the deposited solids, together with corrosion products, created obstructions in some of the tubes which in turn caused excessive turbulence of the gas stream. This resulted in erosion of the tube wall downstream of the deposits.

As can be seen in the photograph, the tube on the right appeared to have failed

from the outside. It is believed that these types of failures occurred after some other tubes in the lower part of the bundle had failed from internal corrosion and erosion. Since gas pressure inside the tubes was about 75 psig higher than water pressure outside, considerable gas impingement would occur after a tube began leaking and, consequently, external erosion would take place on neighboring tubes.

As noted earlier, tubes in the upper half of the bundle were severely pitted on the outside. An example of this condition is shown in Figure 4. Pitting was deeper at the hot end of the heat exchanger where gas entered and water was discharged. The fairly heavy scale had the following analysis: Ni — nil, Co — 0.2 percent, Cu — 0.16 percent, S — 0.17 percent, Fe — 64.8 percent which indicated that it was almost entirely corrosion product with a slight amount of non-ferrous metal contamination. Metallographic study of the tubes showed a microstructure of spheroidal carbides in a matrix of ferrite grains. The steel is believed to have been spheroidized by heat treatment following the cold drawing operation. There was evidence of carbide segregation with pitting more frequent in these areas. It would seem that this type of structure would be prone to galvanic type pitting. However, since other tubes from different sources had a similar microstructure, it was assumed that this structure was inherent in the manufacturing of cold drawn tubes to obtain ductility.

Other parts of the heat exchanger also showed the effect of the corrosive conditions. The channel cover and channel in contact with discharge gas lost between 0.070 and 0.090 inches in a few months. On the inlet side of the channel no corrosion was noted. The floating head was also corroded to a lesser degree except when a gasket leak caused serious erosion of the gasket faces on the head and tube sheet.

It was apparent after the failures had been investigated that two main problems . 17

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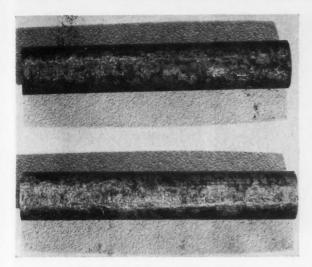


Figure 4—Tubes from upper half of gas cooler.

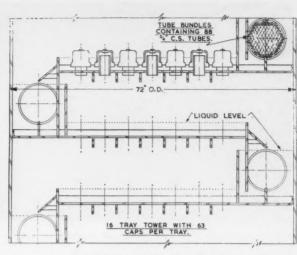


Figure 5-Sketch of original absorption tower.

had to be faced: slurry carryover in the gas from the autoclave and cooling water corrosion. Since repair work on the cooler necessitated a shutdown of the leaching circuit, lost production was an important consideration. When the cooler was first shut down, a by-pass system was installed so that discharge gases would go directly from the autoclave to the tower without being cooled. However, production had to be curtailed somewhat because of the inability of the tower to handle all the hot gas.

An economic evaluation was done in an attempt to estimate the cost of corrosion in the cooler and possible methods for reducing this cost. Three cases were considered:

CASE 1—Yearly cost for retubing exchanger without a spare bundle and by-passing gases while exchanger was out of service.

CASE 2—Yearly cost if a spare car-

bon steel tube bundle were purchased. CASE 3—Yearly cost if a 304 stain-

less steel bundle were purchased.

The following costs were considered in each of these cases:

Item 1-Purchase of spare bundle.

Item 2—Cost of No. 10 gauge replacement tubes.

Item 3—Maintenance labor cost for shutting down, installing by-pass and retubing.

Item 4-Lost production while installing by-pass.

Item 5—Lost production while running on by-pass.

Item 6—Lost ammonia while by-passing gas directly to tower.

Costs given in Table 1 were based on a 10-month life for carbon steel tubes, assuming no decrease in corrosion rate, and a 5-year life for stainless tubes.

The actual purchase cost of a carbon steel bundle was estimated at \$4,200 compared to a stainless one at \$12,000.

These figures show that if corrosion conditions remained severe, there would be no trouble in justifying a stainless

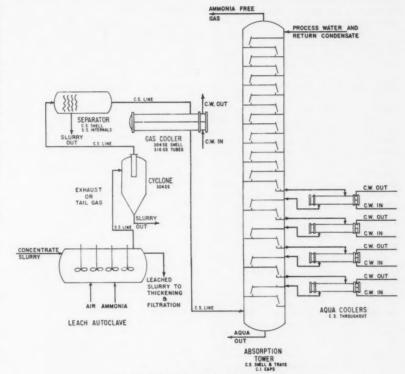


Figure 6—Present ammonia absorption system.

TABLE 1-Projected Cooler Costs

	Case 1	Case 2	Case 3
Cost per year, assuming the cost of the bundle was written off in 5 years.  Actual cost for first year.  Payout period for new bundle.	\$29,700	\$14,880	\$ 5,180 \$18,400 12¾ months

steel tube bundle over five years but the initial cost would be much higher. However, it was decided that a spare carbon steel bundle would be purchased and efforts would be made to reduce corrosion.

To reduce gas side corrosion a demis-

ter was installed in the gas line between the cyclone and cooler. This unit had a carbon steel shell and stainless steel vanes. A special effort was made to decrease corrosion and improve heat transfer on the water side of the tubes. This was accomplished by removing scale with in-

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Figure 7—Corrosion on absorption tower.

hibited hydrochloric acid, flushing and neutralizing the acid, and recirculating a solution of water and water treatment inhibitor in an effort to build up a protective coating on the tubes.

The cooler operated until 1956 without any failures. However, at this time plans were being made for plant expansion and it was obvious that the cooler could not handle any additional load, partly because of waterside fouling and corrosion of the tubes. Although the inhibitor treatment had helped somewhat in reducing corrosion, there was still enough contamination of the water from other sources that the treatment did not remain effective. The inherent corrosiveness of the water was also increased in this cooler because of suspended solids settling out on tubes from the slowmoving water. The demister in the gas stream was fairly effective in removing entrained solids but the small amount left, together with aqua produced in cooling the gas, still caused a little erosion in the unit.

Early in 1956 a larger cooler was purchased to handle an increased flow of gas resulting from increased production. This cooler was designed to have water on the inside of the tubes and gas on the outside which is always a preferable design when water contains any solid matter. Since the outside of the tubes and the shell were to be in contact with gas which could occasionally carry over corrosive entrainment and since the unit was critical from a production standpoint, the tubes and shell were purchased in 316 and 304 stainless steel respectively. This has proven to be a wise decision since no production has been lost because of this unit in the five years that it has been in service.

#### Scrubber

At the same time as troubles were being experienced with the tail gas cooler, problems also developed in the scrubber. A detailed sketch showing the design of scrubber trays is shown in Figure 5. Leaking tubes developed in the two lowest tube nests and corrosion of decreasing severity was evident on tubes in the next six bundles. General vessel

corrosion and scaling was noted in the area occupied by the lower three trays. All eight of the lower tube nests were retubed in 1955.

By processes similar to those used in the investigation of the cooler, it was determined that failure of the tubes was caused primarily by entrainment in the entering gas. Corrosion on the water side of tubes was a secondary factor. Entrainment in the gas was transferred to the aqua in the lower trays and settled out in the wells around the tubes where aqua flow was not fast enough to carry solids over the baffle to the next level. These solids, primarily sulfides, then created perfect corrosion conditions on the tubes causing severe pitting and concentration cell attack at the baffles. The solids also scaled up the walls in the lower areas and caused considerable corrosion.

Economic evaluation showed that if the existing corrosion conditions had persisted, the two lowest tube nests should be retubed in stainless steel and effort should be made to reduce entrainment. Therefore, the addition of the entrainment separator ahead of the cooler was necessary, also to protect the tower. Several cleanout ports were installed so that accumulated solids could be cleaned out from around the tubes.

Before the results of these changes could be properly evaluated, it was necessary to install a larger tower because of increased production. However, because of the troubles encountered with the other tower and the results of subsequent investigations, changes were made in the new tower design. Since process design calculation had shown that cooling was not required on each tray, only the aqua on alternate trays from number 24 to 16 was cooled. External coolers that could be isolated during operation were used in case any tubes required replacement. This design also prevented solids from being lodged on

Manholes were provided between trays to facilitate inspection and repair at any location, without the necessity for going through the whole tower. A large flange was installed so the tower could be easily taken apart between the third and fourth trays. It was hoped that if serious corrosion did occur in the lower trays, the tower could be taken apart for repairs.

The new tower was installed in June, 1956 and, since that time, the old tower has been used to scrub vent gases from various tanks, filters, etc. With the new tower installed the revised ammonia recovery circuit was as shown in Figure 6. The only change since then has been the installation of a larger cyclone.

#### Carbon Dioxide Corrosion

Absorption Tower

In February of 1957 after 8 months service, the new absorption tower was inspected and found to be in perfect condition with no sign of corrosion, scaling, or sulfide deposits. In June, 4 months later, a routine inspection during the annual shutdown revealed very uneven scaling from tray 24 up to tray 21 and somewhat lighter scaling at the 19th tray level. In general, this scale was black, heavy and magnetic. But in places where it was particularly thick, there was a white mushy material under the black scale. This white material was not stable when it was uncovered but partly disappeared and gradually turned light brown. Scaling was very peculiar in that it hung like stalactites from random spots on the underside of trays 23, 22, and 21 and covered the shell of the tower about half-way down to the top of the next lower tray. Iron content of the black scale was 66.8 percent.

Under the scale, corrosion was very uneven and severe with general metal loss of nearly ½ of an inch, and pitting or grooving up to 3/16 of an inch. Corrosion was most severe between trays 24 and 23 and least between trays 20 and 19. Four holes were drilled in the shell for caliper measurements and numerous audigage thickness readings were taken. Typical corrosion is shown in Figure 7.

Operating conditions in the leach system were reviewed and it was found that two changes had been made since the previous shutdown. The water supply to the tower had been altered to include some recycle condensate from ammonium sulfate crystallization and carbon dioxide gas additions had been started into the leach slurry ahead of the adjustment leach autoclaves to precipitate calcium as the carbonate from leach solutions. It was believed that carbon dioxide was responsible for the corrosion; but it was not known whether the condensate was a contributing factor because it was known to contain ammonium sulfate and a small amount of oil.

Plans were immediately made to replace a section of the tower since shell corrosion was well beyond the corrosion allowance and numerous risers were nearly perforated. Carbon dioxide injection and condensate feed were discontinued. A photograph of the replacement operation in August of 1957 is shown in Figure 8. The tower was then operated until February, 1958 without "contaminated" condensate feed or carbon dioxide addition in the leach slurry and it showed no sign of corrosion. Condensate

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Figure 8-Replacement of tower section.

feed was then resumed until June when the tower was again inspected during the annual shutdown. Since no scaling or corrosion was evident, it had been proven conclusively that carbon dioxide was entirely responsible for the corrosion.

Unfortunately, carbon dioxide additions had to be started again in July because of process conditions. An attempt was made to avoid trouble in the tower by feeding the carbon dioxide into the solution after the adjustment leach autoclave. However, an inspection in March of 1959 revealed scaling and corrosion in the new section. It was suspected then that carbon dioxide was distilled from leach solutions in the copper removal circuit and was recycled with aqua to the leach autoclaves where it was picked up by leach gases.

Since the cause of corrosion could not

be eliminated, a means of protecting the tower was desirable. Therefore, a trial patch of an epoxy mastic coating was put in the worst area of the tower and in July of 1959 it was still in good condition. A more extensive coating program was undertaken to include the shell area below trays 23, 22, and 21 and the risers in these trays. A year later a careful examination of the coating revealed that it had not been appreciably attacked by the corrosive media. However, there were numerous little blisters present which contained what appeared to be aqua ammonia but there was no corrosion under the blisters.

In some risers where surface preparation had not been too satisfactory, there were breaks in the coating which had allowed corrosion to progress. The wall area was sandblasted again and recoated with two coats of the same epoxy, but nothing was done with the risers because it was too difficult to get good surface preparation in them. The main thought was to protect the shell to maintain its pressure rating and repair the trays when it became necessary.

Even though it would be possible to coat the tower for a number of years before the cost would be equal to a stainless steel replacement section, consideration is being given to this replacement at the present time. The annual shutdown in the past has generally lasted between 7 and 10 days which, if continued in the future, would be enough time to do the coating work. However, this shutdown time may be reduced or perhaps even eliminated in the leach plant and, if this is the case, the time would not be available for coating work.

#### Corrosion Theory

While the tower was kept in operation as outlined, work was being done to develop a reasonable theory as to the type of corrosion. Unfortunately, carbon dioxide analyses were not done on a regular basis but, instead, control of additions was on the basis of calcium analyses. Some spot checks have been done which indicate the carbon dioxide concentrations at a few locations:

Copper Boil Vapor 1.5 to 1.7% by vol.

Copper Boil Con-

denser Aqua 23.5 to 86.5 g/l

0.0

Tail Gas Absorption Scrubber

Aqua

2.3 to 7.2 g/l

Gas to Absorption Scrubber

These figures substantiate the premise that carbon dioxide is distilled from leach solutions and absorbed in the condensed aqua which is then recycled to the leach circuit. Even though no CO<sub>2</sub> was reported in the gas to the tower, it must be present since it shows up in the tower aqua. Either the analytical method is not sensitive enough or the CO<sub>2</sub> is being condensed along with water and ammonia in the tail gas cooler and being carried in droplet form to the tower. Calculations indicate that the tail gas should contain about 0.1 percent by vol. of CO<sub>2</sub> to produce the observed concentration in the aqua.

Corrosion reactions within the tower are not clearly understood but a theory is proposed on the basis of the following facts:

 Corrosion and scaling occurred only on the underside of trays, inside of risers, and on the shell close to the underside of trays.

2. White scale next to the metal was not stable and also reacted in acid to produce CO<sub>2</sub>.

3. Brown scale appeared to be Fe<sub>2</sub>O<sub>3</sub>.

4. Black, magnetic scale on the surface was Fe<sub>2</sub>O<sub>4</sub>.

5. Temperature of aqua to coolers is about 95 F and from coolers about 65 F.

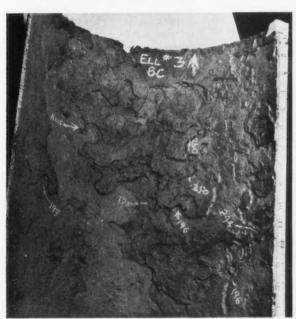


Figure 9-Pipe line corrosion.

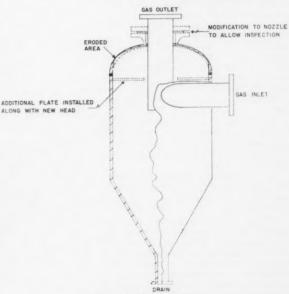


Figure 10-Cyclone erosion.

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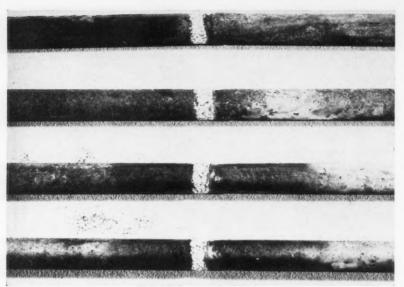


Figure 11-Tubes from copper boil condenser.

Cooled agua is returned to trays 23, 21, 19 and 17

6. Carbon dioxide concentration in aqua at different levels was as follows:

											g	/1 CC
Disch	arge	aqua										
Tray	No.	22				*	*		*	*		
Tray	No.	20								*		1.0
Tray	No.	18						×				0.8
Tray	No.	16										0.5
Inlet	Wate	er										0.2

In general, corrosion is believed to be caused by the condensation of a compound of CO2 and NH3 on the underside of the lower trays, especially trays 23 and 21 which receive cold aqua from the coolers and also show the severest corrosion, Lesser condensation and corrosion occur under tray 22 which is not cooled. At the present time it would appear that there is insufficient CO2 above tray 21 to cause corrosion. However, at an earlier time there was sufficient CO, to cause corrosion under tray 19 which also received cold aqua. It is believed that the CO2 - NH2 compound may be either ammonium carbamate or ammonium carbonate or a mixture of the two. The author believes there is some carbamate present for the following rea-

(1) Mellor5 states that ammonium carbamate has been formed on the walls of a container by passing a mixture of CO3 and NH3 through a concentrated ammonia solution.

(2) The presence of ammonia hinders the conversion of carbamate to carbonate and favors the conversion of carbonate to carbamate.

(3) In the production of urea, carbamate is very corrosive. Even though the temperature in this case is well over 300 F, it may be true that carbamate is also corrosive at lower temperatures. Carbonate, on the other hand, is reported to be only mildly corrosive to steel at temperatures up to 200 F.

The corrosive condensate which forms on the underside of the tray and in the risers, drips back on to the liquid in the tray below and is perhaps partly revaporized. At the edge of a tray the condensate would run down the shell causing corrosion until, if it is carbamate, it is no longer reactive or is picked up in droplets of aqua ammonia. Initial products of corrosion may be a white ferrous carbonate or ferrous hydroxide, both of which could be partly oxidized to ferric hydroxide.

Mellor5 states that magnetic Fe3O4 results from the reaction of ferrous and ferric hydroxides. One must be dissolved. Ferric hydroxide is insoluble in water and ammonium salts but ferrous hydroxide is easily soluble in an excess of ammonium salt. The combination of the two hydroxides is therefore brought about by the precipitated ferrous hydroxide dissolving, and in this state, penetrating and diffusing through the ferric hydroxide. The combination occurs slowly if there is no great excess of the ammonium salt but with much greater rapidity in the presence of considerable excess. Stalactites of hollow magnetic iron oxide would thus be formed underneath trays from corrosion of the tray and risers, while a groove type of corrosion with identical corrosion products would be caused on

Corrosion of the carbon steel line carrying gas to the tower seems to support the theory that condensation of the corroding agent is the basic mechanism of corrosion in the tower. In a short section of this pipeline, corrosion was severe as shown in Figure 9. Note though that such attack occurred only on the upper half of the line. Scale was similar to that described in the tower with only the odd patch of white material next to the metal. All the rest of the line was in good condition with no scaling and very little corrosion. The only explanation that could be given for this corrosion was that the corroded section of pipeline was located in such a way that the top area was cooled by an air draught from open windows about 10 feet above the been very severe, it must have been enough in evidence to cause condensation on top of the line.

#### Cyclone

After about five years of service the original stainless steel cyclone was re-moved and replaced with a larger one. The old model was still in good condition at time of repacement. In one year the head of the new cyclone was leaking and found to be badly eroded as shown in Figure 10. It was concluded that solids were being trapped in the head area and while trying to descend, possibly were picked up by the gas stream to produce excessive turbulence. A new head was installed in such a way that an inspection could be carried out in the future. A carbon steel ring was installed, as shown by the dotted lines, in an attempt to eliminate the erosion.

Only those problems associated with the recovery of ammonia from exhaust air have been discussed in this paper. Other similar problems of solid carryover and carbon dioxide corrosion occurred in the copper boil condenser which condenses ammonia and water vapor distilled from leach solutions. Both the shell and tube bundle of this unit were eventually replaced by 304 stainless steel. A photograph of carbon steel tube corrosion is shown in Figure 11. Note the severe metal loss which occurred at the baffles because of concentration cell corrosion. Elsewhere in the leaching circuit, corrosion problems have been at a minimum because of valuable material of construction data obtained during pilot plant investigations. None of the problems has caused appreciable lost production inasmuch as repairs and inspections could be scheduled without the necessity for such interruption.

#### Acknowledgment

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# Evaluation of Tantalum, Molybdenum And Beryllium For Liquid Bismuth Service\*

By J. W. SEIFERT and A. L. LOWE, Jr.

#### Introduction

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m. ry of es THE INITIAL selection of tantalum, molybdenum and beryllium for the containment of liquid bismuth in a liquid metal fuel reactor was based on a number of widely diversified investigations. As early as 1951, experiments had been conducted to study the compatability of tantalum and bismuth at 1000 C for 100 hours. These tests showed tantalum to be stable. Later a series of extensive corrosion tests were operated at Ames Laboratory in the temperature range of 850 C—1000 C for periods up to 5,000 hours. A, 5, 6 The bismuth in this case contained 5 weight percent uranium. The tantalum had an average corrosion rate of less than one mil per year as determined from these tests.

Investigations by Parkma and Shepherd<sup>7</sup> found that bismuth at 1000 C did not appreciably attack molybdenum in 200 hours. These data were confirmed by Reed after testing for one week at 1000 C and Coultas found the same to be true after 167 hours at 1000 C.<sup>3</sup> Oak Ridge carried out experiments in 1950 and found that bismuth containing 2 percent uranium did not attack molybdenum at 1000 C in four hours.<sup>1,2</sup> Cordovi<sup>9</sup> exposed molybdenum to a 0.4 weight percent uranium in a bismuth solution at 500 C for 2,000 hours and found a corrosion penetration of 3.3 mils/year.

There are very little data on the corrosion of beryllium by bismuth. Kitzes<sup>10</sup> had reported that beryllium was not at acked by bismuth in a 5 hour test at 1000 C. Cordovi<sup>9</sup> reported that beryllium resisted attack by bismuth-lead eutectic containing 2 weight percent uranium for 1,000 hours at 550 C, but did not conduct any work with unalloyed bismuth.

From these data it was apparent that the materials were suitable for the containment of bismuth. However, the parameters used in these test programs varied over a wide range of temperatures and test parameters such that correlation of the data with anticipated design parameters was questionable. As a result, tests were conducted under both static and dynamic conditions incorporating the parameters which had been selected for the reactor. These conditions included the use of liquid bismuth containing uranium, magnesium and zirconium as the fuel solution operating at a maximum temperature of 975 F, a minimum of 750 F with a resulting tem-perature difference of 225 F. The results of these tests would be used to correlate existing data and to produce supplementary data where needed to better establish design problems.

#### Abstract

Abstract

Laboratory capsule tests were made to determine the suitability of tantalum, molybdenum and beryllium for the containment of liquid bismuth in a liquid metal fuel reactor. All the materials tested had adequate corrosion resistance at 750 F and 975 F. The corrosion resistance of tantalum appeared to be related to the sufface finish, with welding having no effect on the material's corrosion resistance. Increasing velocity seemed to adversely affect the corrosion resistance of molybdenum + 0.5 Ti but had no effect on tantalum. Beryllium did not appear to be affected by velocity in the range studied.

4.7, 6.3.13, 6.3.9

#### Testing Procedure

Capsule Testing

The tilting capsule is shown in Figure 1. The capsules were constructed of 2½ Cr-1 Mo steel, ¾ inch-schedule 40 pipe; they contained two corrosion specimens at each end. The specimens were of the flat plate type, measuring 2 inches long, 0.5 inch wide and 0.0625 inches thick. The ends of the capsule were sealed by inserting end caps which contained the controlling and indicating thermocouples. Before the welding of the final end cap, a sufficient quantity of bismuth and additives were placed in the capsule to insure complete liquid submersion of the corrosion specimens.





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The temperatures of the ends of the capsules were maintained by separate tubular type electric furnaces which were individually controlled.

The capsules were tilted from end to end with temperature equilibrium at

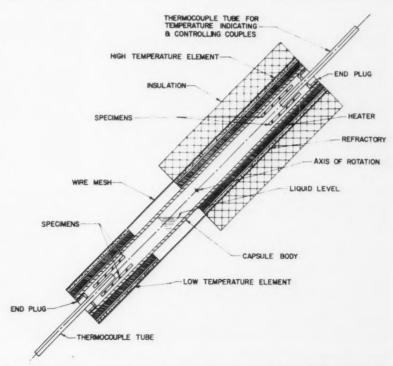


Figure 1—Schematic of tilting capsule apparatus showing important components and location of test specimens.

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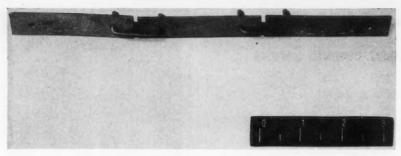


Figure 2—Photograph of flat specimens placed in dynamic test loops to evaluate corrosion resistance of various materials.

each end of the cycle, thus permitting the solution to flow between the two ends and allow the necessary times for solution, mass transfer, or corrosion to take place. The time for a complete cycle was five minutes with the temperature reaching equilibrium in approximately one minute after completion of the tilt. The specimens were at each of the two test temperatures approximately 11/2 minutes of the total cycle time. The test duration was 1,000 hours with a maximum solution temperature of 975 F at one end of the capsule and a minimum temperature of 750 F at the other end.

#### Dynamic Loop Testing

The dynamic testing of the materials was conducted by placing flat specimens as shown in Figure 2, in pumped loops used to demonstrate the suitability of the primary container materials. These loops were designed to simulate an actual reactor primary system with respect to temperature, velocity, temperature differentials and additive concentration. With the exception of velocity, the conditions of the loop test were similar to those used in the capsule tests.

The loops were fabricated from 3/4 inch schedule 40-21/4 Cr-1 Mo steel pipe of all welded construction. The circuit consisted of a heater, regenerative heat exchanger, cooler, pump and sampling and control sections.

The maximum temperature in the loop was 910 F which was at the exit of the heater section (the location of the molybdenum, tantalum and beryllium test specimens). The minimum temperature was 775 F at the cooler exit. The liquid bismuth used in the loops contained the same concentration of additives as the bismuth used in the capsule tests. The velocity of the molten bismuth was held constant for the test period and a separate test loop was used for each of the two test velocities, 4 feet per second and 8 feet per second. The velocities were established to determine the effect of this operating parameter on corrosion. For this reason, the only variable in the dynamic tests was velocity.

**TABLE 1—Chemical Composition of** Materials\*

	COMPOSITION, PERCENT											
Element	Tan- talum(1)	Molybdenum + 0.5 Ti(2)	Beryl- lium(3)									
Mo Be Ta	99.90	99.43	99.30									
C Ti BiO Fe	0.03	0.023 0.540	N.A. 0.116									
Al Mn Ni Cr			0.045 0.007 0.012 0.014									

\* As Reported by the Manufacturers. N.A. = Not Available. (1) Fansteel Metallurgical Corporation. (2) Climax Molybdenum Company. (3) Brush Beryllium Company.

#### Materials

The materials used, tantalum, molybdenum - 0.5 percent titanium alloy, and beryllium, were of a commercial grade without any special processing. Both molybdenum and tantalum were vacuum arc cast and rolled. The beryllium was an extruded product. The chemical compositions of the materials as reported by the manufacturers are given in Table 1.

The bismuth used in these tests was 99.999 percent purity. Additives of 1150 ppm natural uranium to simulate the fuel, 350 ppm magnesium as an oxidizer to protect the uranium, and 175 ppm zirconium as a corrosion inhibitor were added to make up the fuel solution.

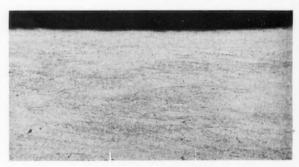
#### Specimen Surface Preparation

The as-received material was used as a basis for comparison of corrosion rates and as a result no special processing or heat treatment was performed on the





Figure 3—Photomicrographs of tantalum specimens in the as-received condition (top specimen) and after exposure to liquid bismuth for 1000 hours (bottom specimen). Etchant: HF plus NHIF, 250X reduced to 150X.



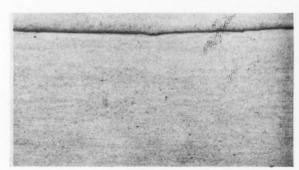


Figure 4—Photomicrographs of molybdenum plus 0.5 Ti specimen in the as-received condition (top specimen) and after exposure to liquid bismuth for 1000 hours (bottom specimen). Etchant: NaOH plus K.F.e (CN)e; 250X reduced to 150X.

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material after final processing by the manufacturer.

The sand blasted specimens were prepared using alumina particles while the rough and fine polished specimens were prepared using Size 1 and Size 000 grit paper, respectively. The welded specimens were prepared by making a tungsten-arc inert-gas shielded weld pass without filler metal along the length of the specimen.

#### Cleaning Procedure

The specimens were cleaned after the surface preparation was completed by a simple degreasing operation consisting of washing in acetone and drying. The specimens were then weighed and placed in the test apparatus.

The cleaning procedure used to remove the adherent bismuth from the specimen after testing was to submerge the specimen in two separate baths of mercury followed by a nitric acid dip. The nitric acid was found to be necessary in order to remove unwanted material from the specimen surfaces. The molybdenum specimens could not be cleaned in this manner because of the susceptibility of molybdenum to attack by nitric acid. It was found that inhibited hydrochloric acid was a satisfactory substitute. These cleaning procedures were studied with untested specimens of the materials and it was found that the average weight loss per specimen for the molybdenum was 0.6 mg, for the tantalum 0.3 mg, and no measurable loss for the beryllium. Following the cleaning operation, the specimens were weighed and examined metallurgically.

#### Results of Capsule Tests

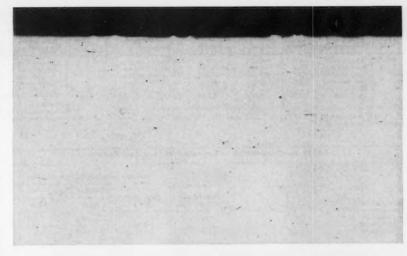
#### Tantalum

Tantalum data obtained from the capsule tests are presented in Table 2. Although the number of specimens tested was limited, the results show the excellent corrosion resistance of the material. A slight trend was observed from these data at 975 F. It appears that the finer the finish, the lower the corrosion rate for both the as-received and the as-welded specimen. The same trend was not observed for the data obtained at 750 F. However, it was not anticipated that any corrosion would take place at the lower temperature. In either case, the corrosion rates for the various preparations are to be considered insignificant.

For comparison purposes, photomicrographs of representative tantalum specimens are presented in Figure 3. The top micrograph is of the as-received tantalum which had not been exposed to the liquid bismuth. The lower specimen is also in the as-received condition but after exposure to the test medium for 1,000 hours at 975 F. There is no surface effect on the specimen, a condition which would be expected from the corrosion data.

#### Molybdenum + 0.5 Percent Titanium

The test data obtained for molybdenum alloyed with 0.5 percent titanium is presented in Table 3. These data in-



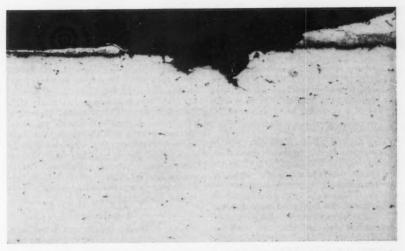


Figure 5—Photomicrographs of beryllium in the as-received condition (top specimen) and after exposure to liquid bismuth for 1000 hours (bottom specimen). Unetched; 100X.

dicate the corrosion resistance of the alloyed molybdenum to be excellent for the various surface preparations. In this case, it appears that as a finer surface preparation was used the greater the corrosion rate; however, even the increased rate is sufficiently small to be considered insignificant for design purposes.

Figure 4 shows representative photomicrograph of the alloyed molybdenum specimen in the as-received condition both before and after testing. There is no evidence of any surface attack of the material as a result of exposure to the liquid bismuth at 975 F for 1,000 hours.

#### Beryllium

The beryllium was tested in the asreceived condition only and the data are presented in Table 4. Of the three materials tested, beryllium had the highest average corrosion rate; however, it is low enough as not to be detrimental for design applications.

Figure 5 contains representative micrographs of beryllium specimen in both tested and untested conditions. The tested specimen shows a section through a part of the spalled surface of the specimen. This surface condition does not appear

TABLE 2—Tilting Capsule Tests of Tantalum\*

		Test	Ave. Penetration, Mil/yr					
Test No.	Specimen Preparation	Time, Hours	975 F	750 F	Remarks			
1 2	As-received Sand blasted Rough polished Fine polished	1000 1000 1000 1000	-0.013 -0.006 -0.001 -0.003	-0.003 -0.011 -0.001 -0.009	No visible attack No visible attack No visible attack No visible attack			
5	Welded, as-received Welded, sand blasted Welded, rough polished Welded, fine polished	1000 1000 1000 1000	$\begin{array}{c} -0.015 \\ -0.028 \\ -0.001 \\ -0.006 \end{array}$	0.005 0.008 0.001 0.001	No visible attack No visible attack No visible attack No visible attack			

<sup>\*</sup> Test Solution = Bi + 1150 ppm U, 350 ppm Mg, 175 ppm Zr; Test Temperatures: 750 F and 975 F.

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TABLE 3—Tilting Capsule Tests of Mo  $\pm$  0.5 Percent Titanium\*

75	6	Test	Ave. Penetration, Mil/Yr							
Test No.	Specimen Preparation	Time, Hours	975 F	750 F	Remarks					
1, 2, 3, 4, 5,	As-received Sand blasted Sand blasted Fine polished	1000 1000 1000 1000	$     \begin{array}{r}       -0.002 \\       -0.003 \\       -0.004 \\       -0.051     \end{array} $	$\begin{array}{r} -0.014 \\ -0.023 \\ -0.002 \\ -0.011 \end{array}$	No visible attack No visible attack No visible attack No visible attack					
5.	Electro polished	1000	-0.056	-0.040	No visible attack					

\* Test Solution: Bi + 1150 ppm U, 305 ppm Mg, 175 ppm Zr; Test Temperature: 750 F and 975 F.

TABLE 4-Tilting Capsule Tests of As-Received Bervillium\*

T	Specimen	Test Time.	Ave. Penetration, Mil/Yr							
Test No.	Preparation	Hours	975 F	750 F	Remarks					
1. 2. 3. 4.	As-received As-received As-received As-received	1000 1000 1000 1000	-0.153 -0.504(a) Lost -0.683(a)	-0.313(a) -0.332(a) -0.990(b) -0.045	No visible attacl No visible attacl No visible attacl No visible attacl					

\* Test Solution: Bi + 1150 ppm U, 350 ppm Mg, 175 ppm Zr. (a) Small particles of specimen adhered to specimen holder upon removal. (b) Part of specimen broke off during cleaning.

TABLE 5-Comparison of Capsule and Loop Test Data\*

		Average (	Average Corrosion Rate, Mil/Yr				
Material	C1	C1-	Dynamic Loops-910 F				
	Specimen Preparation	Capsule— 975 F	4 fps	8 fps			
Tantalum	As-received As-received As-received	-0.013 -0.003 -0.504	0.009 0.019 2.390	0.004 0.229 0.690			

\* Test Solution = Bi + 1150 ppm U, 350 ppm Mg, 175 ppm Zr.

to be the result of corrosion but probably can be attributed to removal of the adherent bismuth during the post test cleaning procedure. The ragged appearance of the spalled area indicates a tearing away of the beryllium as a result of removing the solidified bismuth and does not represent the smooth type of surface typical of a corroded or eroded area.

#### Results of Dynamic Tests

The data obtained from the capsule tests were verified by data obtained from placing tabular specimens in a dynamic test system which more closely simulated the environment expected in a reactor system. These data are presented in Table 5 and are compared with the capsule data for specimens with the same preparation and the same test temperature. It should be noted that the dynamic data are for two different velocities, 8 feet per second and 4 feet per second.

The effect of velocity was greatest on the results from the alloyed molybdenum. The corrosion rate for the material increased several fold with the increase in the velocity of the test fluid from 4 fps to 8 fps. It is probable that the data

obtained at a test velocity of 4 fps may contain experiment error in that the weight gain observed for the molybdenum specimen might be attributed to the cleaning process. Likewise, the beryllium specimens may have been chipped during handling after the initial weighing, thus resulting in an abnormally high corrosion rate. The tantalum showed a progressive decreasing corrosion rate with increasing velocity. Except in the case of the beryllium, the variations in the data from the tantalum and alloyed molybdenum are of sufficiently small magnitude as to be considered negligible when compared with the low corrosion rates observed.

#### Conclusions

The following conclusions have been made from the data presented on the corrosion resistance of the various materials studied:

1. All the materials had adequate corrosion resistance at 750 F and 975 F (less than 1 mil/yr) for design purposes.

2. The corrosion resistance of tantalum appears to be related to the surface

3. Welding had no effect on the corrosion resistance of tantalum.

4. Increasing velocity appears to adversely affect the corrosion resistance of molybdenum + 0.5 Ti but has no effect on tantalum.

5. Beryllium does not appear to be affected by velocity in the range studied.

#### Acknowledgement

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Any discussion of this article not published above will appear in December, 1961 issue.

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## Effect of Nitrogen Tetroxide On Metals and Plastics\*

By C. W. ALLEY, A. W. HAYFORD and H. F. SCOTT, JR.

#### Introduction

STUDY was made to determine A quantitatively the corrosion of several metals and alloys in dry and wet liquid nitrogen tetroxide between the temperature limits of —9 to 74 C. This paper summarizes the data from static tests on carbon steel (ASTM A-285, Grade C), stainless steel (304-L), aluminum (5086), welded aluminum (5086), titanium (75A and 6Al-4V), and high strength steel (PH15-7 Mo). The durability of a number of elastomers was determined at 25 C. Data also are presented from several dynamic tests conducted by pumping commercial nitrogen tetroxide through a system containing carbon steel, stainless steel, high strength steel, aluminum, polytetrafluoroethylene and polychlorotrifluoroethylene.

#### Materials Involved in Study

Nitrogen tetroxide is a heavy brown liquid at ordinary temperatures containing about 30 percent nitrogen and 70 percent oxygen. In this form it consists principally of the tetroxide (N2O4) in equilibrium with a small amount of nitrogen dioxide (NO<sub>2</sub>). This product is available in commercial quantities in very pure form containing less than 0.1 percent water. Nitrogen tetroxide is an economical and reliable storable liquid oxidizer for liquid-fueled rockets. A 2000pound cylinder of commercial N2O4 was obtained for these tests and analyzed with results shown in Table 1.

Metals. The metals with mill tests, or certified analyses, are shown in Table 2.

#### Equipment and Procedure

Initial static corrosion tests were conducted in Teflon-lined aluminum containers. Because of the adverse effect of Teflon on the corrosion of carbon steel and stainless steel, the Teflon liners were removed and glass tubes with loose fitting caps substituted as illustrated in Figure 1. Each aluminum container was cooled in an ice bath and 80 cc of liquid N2O4 was added to facilitate heat transfer and to maintain the proper vapor pressure on the outside of the glass tube.

At the same time the desired amount of water was added to the glass tube and 125 ml of liquid N2O4 was poured into the tube. The tube containing the N2O4 and the metal specimens suspended on a glass tree was lowered into the container, a glass cap placed on the tube and the container closed. The loaded containers were placed in thermostatically controlled baths at -9, 21, 49 and 74 C. Tests





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#### Abstract

Abstract
The corrosion rates of carbon steel, stainless steel (304-L and PH 15-7 Mo), aluminum (5086), and titanium (75A and 6AI-4V) in dry and wet nitrogen tetroxide were determined under static conditions of exposure at -9 C to 74 C. Carbon steel and aluminum were attacked in proportion to water concentration and temperature. Stainless steel 304-L and titanium were unattacked, and PH 15-7 Mo only slightly attacked. Significant corrosion of stainless steel (304-L) occurred in the presence of TeHon. Corrosion by dry nitrogen tetroxide under flow conditions was negligible. TeHon was the most resistant of the plastics exposed to nitrogen tetroxide.

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were run in commercial N<sub>2</sub>O<sub>4</sub> having 0.0, 0.2, 0.4, 0.8, 1.6, and 3.2 wt percent water added.

Exposure times were 3, 9 and 27 days, each starting from zero time. This is a condition encountered in a single filling of a storage vessel. After the desired period of exposure, the containers were removed from the bath and chilled in ice water. The specimens were removed, scrubbed with a bristle brush in water, rinsed in acetone, then dried and weighed. The liquid N<sub>2</sub>O<sub>4</sub> was observed for sludge formation, etc., but not reused. The specimens were reused after resur-

facing, cleaning and weighing.

The procedure for testing welded aluminum was similar to that using glass tubes except that only one specimen was placed in each tube. Glass trees were not used and the specimen was allowed to rest in the vertical position on the bottom of the tube. Tests were conducted with N<sub>2</sub>O<sub>4</sub> containing 0.0, 0.4, and 3.2 wt percent water at —9, 21 and 74 C. Specimens were weighed before and after testing and those corroded were examined microscopically around the welded area cross section.

TABLE 1-N:O4 Analysis and Specification

	Analysis	Specification
N2O4 Assay, Wt. %	99.9+	99.5
H2O Equivalent, Wt.%	0.004	0.1 Max.
Cl as NOCl, Wt. % Nonvolatiles (Ash),	0.002	0.08 Max.
Wt. %	0.0008	0.01 Max.

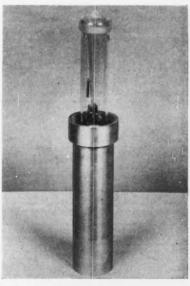


Figure 1-Glass tube and aluminum container.

<sup>★</sup> Submitted for publication January 6, 1960. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, March 13-17, 1961.

Titanium specimens were tested in stainless-steel containers 12 inches deep and 4 inches in diameter. Specimens were mounted on a carrier attached to the container head. Glass was used to insulate the specimens from each other and from the stainless steel. Grades 75A and 6Al-4V titanium were statically tested in  $N_2O_4$ , containing six water concentrations, at 21 C for 27 days and at 74 C for 9 and 27 days. Each stainless-steel container was fitted with a blowout diaphragm, a dip-pipe line and a vent line.

N<sub>2</sub>O<sub>4</sub> containing the desired amount of water was loaded into the containers via the dip-pipe lines which were extended to a remote station.

After the exposure period, the dip-pipe lines were opened and the N<sub>2</sub>O<sub>4</sub> discharged. Argon was blown in the dippipe lines and out of the vent lines until all traces of N<sub>2</sub>O<sub>4</sub> disappeared. The containers were valved off, cooled and carefully removed from the bath. They were opened, the specimens removed, scrubbed in water, dried and weighed.

Stress corrosion tests also were conducted in stainless-steel containers. The loaded containers were placed in a bath with the temperature controlled at 49 C  $\pm$  0.5 throughout two period of exposure totalling 41 days. After the first exposure period of 14 days, the specimens were cleaned and visually examined for cracks. The same specimens and liquid were used

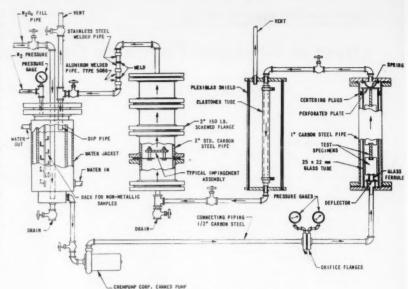


Figure 2—Recirculating unit—assembly and views.

in both tests. At the conclusion of the second period of exposure the specimens were cleaned, mounted and microscopically examined.

Dynamic tests were conducted in the recirculating system shown in Figure 2.

Carbon steel, aluminum, stainless steel and precipitation hardened steel specimens were mounted one above the other in a glass tube fitted inside a vertical metal pipe. Each specimen was separated from a dissimilar metal by a Kel-F ferrule to minimize galvanic effects. Kel-F

#### **TABLE 2—Certified Mill Tests of Metals**

Material	Purchased From	Sheet No.	Heat No.					СНЕМ	ICAL CO	MPOSIT	ION				
Carbon Steel ASTM A-285 Grade C Firebox Steel	Morris, Wheeler Co., Philadelphia, Pa. Order No. HNR24691	-285 Grade   Philadelphia, Pa.	-285 Grade   Philadelphia, Pa.	47281	0.16	Mn 0.37	P 0.016	S 0.030							
Type 304 ELC Stainless Steel	Steel Specialties, Inc. Order No. HNR24753		E86598	C 0.024	Mn 1.38	P 0.025	S 0.012	Si 0.59	Cr 18.90	Ni 10.64					
Aluminum Alloy 5086-H34	Reynolds Metal Co. Louisville, Ky.*			Si 0.40	Fe 0.50	Cu 0.10	Mn 0.2-0.7		Mg 3.5-4.5	Cr 0.05-,25	Zn 0.25	Others Each 0.05	Others Total 0.15	Al Remainde	
Titanium-Grade 75A	Titanium Metals Co. of America, New York, N.Y. Order No. HNR25450	4-2	M-9082	0.026	Fe 0.28	N <sub>2</sub> 0.033	H <sub>2</sub> 0.004								
Titanium-Grade 6AL-4V	Titanium Metals Co. of America, New York, N.Y. Order No. HNR25450	12-1	M-8543	C 0.028	Fe 0.17	N <sub>2</sub> 0.011	A1 6.0	Va 4.1	H <sub>2</sub> 0.005						
PH15-7 Mo Stainless Steel	Armco Steel Corp., Middletown, Ohio		56254	C 0.075	Mn 0.60	P 0.021	S 0.006	Si 0.26	Cr 15.14	Ni 7.20	Mo 2.22				
Aluminum Alloy 5086-Welded	Richmond Eng. Co., Richmond, Va.			wel	ding by	the He	liarc proce	ess. Squ	uare butt	sent to Ri ends were	welded	together	with fill	er metal	

		Sheet No.	Heat No.	PHYSICAL PROPERTIES						
Material	Purchased From			Test No.	Yield Pt.	Tensile Strength	Elong- ation	105° Bend Test Press Brake		
Carbon Steel ASTM A-285 Grade C Firebox Steel	Morris, Wheeler Co., Philadelphia, Pa. Order No. HNR24691	A-12	47281		36,700	56,100	31%-8"			
Type 304 ELC Stainless Steel	Steel Specialties, Inc. Order No. HNR24753		E86598							
Aluminum Alloy 5086-H34	Reynolds Metal Co. Louisville, Ky.*									
Titanium-Grade 75A	Titanium Metals Co. of America, New York, N.Y. Order No. HNR25450	4-2	M-9082	A2605 4L T	82,500 87,400	102,200 104,700	21.0 22.0	1.9 1.9		
Titanium-Grade 6AL-4V	Titanium Metals Co. of America, New York, N.Y. Order No. HNR25450	12-1	M-8543	A-1364 12L T	132,400 142,100	142,900 148,500	13.0 12.5	3.6 3.9		
PH15-7 Mo Stainless Steel	Armco Steel Corp., Middletown, Ohio		56254	Condition RH950	219,000 Rockwell C	233,000	5-2"			
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<sup>\*</sup> From Reynolds Aluminum Sheet 2-4-6 dated March 16, 1959.

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TABLE 3—Summary of Corrosion Rates of Metals Tested in Static N<sub>2</sub>O<sub>4</sub> in Capped Glass Tubes and 304-L Stainless Steel Containers

	PENETRATION IN MILS PER YEAR AT INI	DICAT	ED TE	MPER			0.0-3.	2 WEIG	GHT P	ERCE			ADDEI	0
Days In					-9 C	(15 F)					21 C	(70 F)		-
Period	MATERIAL		0.0	0.2	0.4	0.8	1.6	3.2	0.0	0.2	0.4	0.8	1.6	3.2
3 9 27	Carbon Steel ASTM A-285 Grade C		0.52 0.06 0.01	0.42 0.07 0.03	0.32 0.08 0.04	0.33 0.21 0.11	0.39 0.23 0.12	0.57 0.19 0.12	0.22 0.14 0.01	0.18 0.06 0.08	0.08 0.05 0.03	0.49 0.39 0.34	3.40 3.00 3.15	3.91 3.77 4.32
3 9 27	Type 304-L Stainless Steel		0.00 0.01	0.00 0.02	0.00	0.00	0.00	0.00 0.00 0.02	0.00 0.05 0.00	0.00 0.03 0.02	$0.00 \\ 0.03 \\ 0.02$	0.00 0.06 0.02	0.00 0.05 0.03	0.00 0.08 0.03
3 9 27	5086-H34 Aluminum		0.00 0.00 0.00	0.00 0.00 0.00	0.27 0.00 0.07	1.59 2.23 2.57	2.06 3.06 3.07	2.42 4.55 3.61	0.00 0.00 0.00	0.00 0.00 0.01	0.34 0.00 0.15	1.46 0.75 0.79	18.93 8.64 3.07	59.80 15.53 7.20
3 9 27	PH 15-7 Mo Stainless Steel (ARMCO Condition RH 950	))	0.11 0.00 0.00	0.07 0.00 0.01	0.07 0.02 0.01	0.13 0.02 0.02	0.15 0.02 0.02	0.08 0.02 0.00	0.00 0.00 0.00	0.10 0.00 0.00	0.22 0.02 0.00	0.20 0.02 0.00	0.35 0.07 0.04	0.43 0.06 0.03
9 27	75-A Titanium				****				0.00	0.01	0.01	0.00	0.00	0.00
9 27	6A1-4V Titanium				****	****			0.00	0.00	0.00	0.00	0.00	0.01
27	Welded 5086 Aluminum		0.02		1.38			1.65	0.01		0.38			6.65
						1	1							
	PENETRATION IN MILS PER YEAR AT IND	ICAT	ED TE	MPERA	TURE	S AND	0.0-3.2	WEIG	нт Р	ERCEN	T WA	TER A	ADDEL	)
Days In				49 C	(120 F	)				74	C (16	5 F)		
In Period	MATERIAL	0.0	0.2	49 C	(120 F	1.6	3.2	0.0	0.2	0.4	C (16	5 F)	1.6	3.2
In				49 C	(120 F	)	3.2 32.77 44.88	0.0 7 0.58 8 0.06	0.2	0.4 2 0.5 3 0.2	C (16)	5 F) 8 68 6 69 4		
In Period	MATERIAL	0.0 0.47 0.04	0.2 0.29 0.04	49 C 0.4 0.40 0.92	0.8 0.55 6.47	1.6 12.54 19.35	3.2 32.77 44.88 29.72 0.00 0.00	0.0 7 0.58 8 0.06 2 0.03 0 0.00 5 0.10 4 0.17	0.2 0.32 0.06 0.19 0.00	74 0.4 2 0.5 3 0.2 1.1 0 0.0 4 0.0 0 0.0	1 C (16) 7 15. 4 7. 2 3. 0 0. 5 0. 2 0.	5 F)  8   68   6   69   4   25   1   1   1   1   1   1   1   1   1	3.71 2.49 3.50 0.00 0.06 0.00	3.2 166.42 89.33
3 9 27 3 9 27	MATERIAL  Carbon Steel ASTM A-285 Grade C	0.0 0.47 0.04 0.02 0.00 0.06 0.01	0.2 0.29 0.04 0.16 0.00 0.03 0.01	49 C 0.4 0.40 0.92 0.99 0.00 0.02 0.02	0.8 0.55 6.47 5.29 0.00 0.04 0.02	1.6 12.54 19.35 16.49 0.00 0.06 0.02	3.2 32.77 44.88 29.72 0.00 0.00 0.00	0.0 7 0.58 8 0.06 2 0.03 0 0.00 0 0.10 1 0.17 0.02 9 0.67 1 0.00	0.2 0.32 0.00 0.19 0.00 0.00 0.00 0.00	74 0.4 0.22 0.5 0.22 0.23 0.23 0.24 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00	7 15. 4 7. 2 3. 0 0. 5 0. 0 0. 5 0. 2 0. 4 30. 5 15.	8 68 69 4 25 1 000 000 001	3.71 2.49 3.50 0.00 0.06 0.00	3.2 166.42 89.33 27.50 0.12 0.05 0.02
3 9 27 3 9 27 27 27 27 27	MATERIAL  Carbon Steel ASTM A-285 Grade C	0.0 0.47 0.04 0.02 0.00 0.06 0.01	0.2 0.29 0.04 0.16 0.00 0.03 0.01 	49 C 0.4 0.40 0.92 0.99 0.00 0.02 0.02 0.02 1.12	0.8 0.55 6.47 5.29 0.00 0.04 0.02 4.74 8.35	1.6 12.54 19.35 16.49 0.00 0.06 0.02	3.2 32.77 44.88 29.72 0.00 0.00 0.04	0.0 7 0.588 8 0.06 9 0.03 0 0.00 0 0.00 6 0.10 0 0.17 0 0.02 0 0.00 1 0.00	0.2 0.33 0.06 0.06 0.04 0.00 0.00 0.00 0.00 0.00	74  0.4  0.5  0.5  0.2  0.5  0.2  0.0  0.0  0.0	1 C (166 1 0. 7 15. 7 4 7. 2 3. 0 0. 0.5 0. 0.5 0. 15. 15. 15. 15. 15. 15. 15. 15	8 68 669 4 1000 000 001	3.71 2.49 3.50 0.00 0.06 0.00	3.2 166.42 89.33 27.50 0.12 0.05 0.02
3 9 27 3 9 27 27 3 9 27 27 3 9 9 27 3 9 9 27	MATERIAL  Carbon Steel ASTM A-285 Grade C  Type 304-L Stainless Steel	0.0 0.47 0.04 0.02 0.00 0.06 0.01 0.45 0.04 0.00 0.00 0.00 0.00	0.2 0.29 0.04 0.16 0.00 0.03 0.01 0.58 0.36 0.15 0.05 0.03	49 C 0.4 0.40 0.92 0.99 0.00 0.02 0.02 0.02 0.03 0.05 0.12	0.8 0.55 6.47 5.29 0.00 0.04 0.02 4.74 8.35 3.26 0.10 0.11	1.6 12.54 19.35 16.49 0.00 0.06 0.02 37.34 36.39 9.59	3.2 32.77 44.88 29.77 0.00 0.04 75.38 72.01 57.85 0.51	0.0 7 0.588 8 0.062 2 0.03 2 0.03 6 0.10 6 0.10 6 0.10 1 0.00 1 0.00	0.2 0.33 0.06 0.15 0.00 0.00 0.00 0.00 0.00 0.00 0.00	74  0.4  0.2  0.55  0.22  0.05  0.20  1.1:  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00	1 C (164 0.17 7 15,74 7 7.22 3.00 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.0	8 68 69 4 1 1 000 001	1.6 3.71 2.49 3.50 0.00 0.06 0.00 8.33 7.95 7.99 1.81 0.35	3.2 166.42 89.33 27.50 0.12 0.05 0.02 152.51 79.45 48.60 2.10 0.81
In Period  3 9 27  3 9 27  27  3 9 27  27  3 9 27  9 9	MATERIAL  Carbon Steel ASTM A-285 Grade C  Type 304-L Stainless Steel  5086-H34 Aluminum	0.0 0.47 0.04 0.02 0.00 0.06 0.01 0.45 0.04 0.00 0.04 0.00	0.29 0.04 0.16 0.00 0.03 0.01  0.58 0.36 0.15 0.05 0.03 0.03	49 C 0.4 0.40 0.92 0.99 0.00 0.02 0.02 0.35 0.05 0.12 0.00	0.8 0.55 6.47 5.29 0.00 0.04 0.02 4.74 8.35 3.26 0.10 0.11 0.07	1.6 12.54 19.35 16.49 0.00 0.06 0.02 37.34 36.39 9.59 9.59 0.22 0.26	3.2 32.77 44.88 29.73 0.00 0.00 0.04 75.38 72.01 57.88 0.51 0.41 0.14	0.0 0.0 0.58 8 0.06 2 0.03 0 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.	0.2 0.33 0.00 0.15 0.00 0.00 0.00 0.00 0.00 0.00	74  0.4  0.4  0.22  0.55  0.225  0.255  0.225  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000  0.000	7 15.4 7.3 0 0.5 0 0 0.5 0 0 0.0 0 0.0 0 0.0 0 0.0 0.	8 68 69 4 225 1 000 001 61 8 28 3 117 1 37 220 006 001 000 001	3.71 2.49 3.50 0.00 0.06 0.00  8.33 7.95 7.99 1.81 0.35 0.06	3.2 166.42 89.33 27.50 0.12 0.05 0.02 152.51 79.45 48.60 2.10 0.81 0.39

and Teflon tubes were included in the piping. Disks of stainless steel and carbon steel were tested separately with each disk mounted within the vena-contracta above a simple orifice to get impingement effects. Six plastic and three gasket specimens were suspended from a vertical rack in the reservoir. Also included in the piping were weighed ells of carbon steel, 304 stainless steel and aluminum.

Commercial N2O4 was charged until the reservoir filled to the overflow valve. The cooling water was turned on and the pump started to circulate the N2O4. At the conclusion of the first test (about 100 hours) the system was drained and the test specimens were removed. Metal specimens were brushed and washed with water, rinsed in acetone, dried and weighed. Materials from the reservoir were examined for loss of strength and change in appearance. Metal specimens were returned to the system for the second test which was run by the same procedure. At the conclusion of the second test all specimens were examined.

#### Discussion of Results

Static Tests in Capped Glass Tubes

Data from 338 static tests are summarized in Table 3. Weight loss for the three specimens of each test was averaged and the average converted to mils per year. Reference is made to these data in the following paragraphs:

#### Carbon Steel ASTM A-285, Grade C

Temperature had only a slight effect on corrosion rate at 0.4 percent or less water. There was a large increase in rate due to temperature at 3.2 percent water. An eight-fold increase of water did not significantly increase the attack at —9 C but at 21 C and higher the corrosion rate increased many fold. With the exception of the 74 C tests, carbon steel did not exhibit the high initial attack that occurred in the presence of Teflon. No cases of pitting were observed.

#### Stainless Steel 304-L

There was negligible attack on stainless steel except at 74 C where the maximum penetration rate of 0.17 mpy was recorded in a 27-day test containing no added water. In contrast, this metal showed, in the presence of Teflon, penetration rates as high as 4.58 mpy in a 14-day test at 74 C and 3 percent water.

#### Aluminum 5086

With few exceptions, this alloy of aluminum exhibited a greater susceptibility to attack than carbon steel at all water levels and temperatures. At concentrations of less than 0.4 percent water, temperature does not exert a strong influence on the corrosion rate. Above 0.4 percent water and 21 C, both temperature and water concentration contribute directly to the corrosion rate. This was more pronounced in the 3-day test. Where corrosion occurred, it was of the general type with a soft layer of white (green until washed free of  $N_2O_4$ ) corrosion products forming over the entire aluminum surface.

Welded aluminum corrosion penetration rate for the 27-day period in the absence of added water was less than 0.1 mpy, but rose to 32 mpy at 74 C, 3.2 percent water. The weld areas on the corroded specimens were outlined by a visible change in brightness at the junction of the weld and base metals; however, microscopic examination (50 to 400X) of specimen cross sections showed that corrosion was of the general type without visible surface pits or cracks.

#### PH15-7Mo Stainless Steel

This metal suffered very little attack (less than 0.2 mpy in N<sub>2</sub>O<sub>4</sub> containing 0.4 percent water) under all conditions except at 74 C, 1.6 and 3.2 percent water,

-Compatibility of Commercial N2O4 .. .. .. . .

Elastomer	Days In Test	Observations					
Tygon	66	Tubing shrunk to one- half its original size turned dark green in color, and on stand- ing in atmosphere it became hard and would crack when bent.					
Hypalon Rubber Nylaflow Hose Viton "B" Rubber	20 7 9	Disintegrated. Disintegrated. Swelled twice its original size, very soft and much more flexible than original sample.					
Koroseal	9	Tubing showed som shrinkage, turner green in color, and be came hard on stand ing. This tube burs at 1000 psig. (Un tested tubing sweller at 100 psig and burs at 400 psig).					
Hycar 5-T Rubber. Thiokol 3600 ST-C	12	Disintegrated.					
Rubber		Disintegrated immedi- ately on contact with N2O4.					
Acid Seal MA Rubber		Disintegrated immedi- ately on contact with N <sub>2</sub> O <sub>4</sub> .					
Silastic Rubbers: No. 59711-2-480 No. LS-53-24-300.	7 7	Crumbled. Swelled twice its orig- inal size.					
No. 50-24-480 No. 651	7 3	Crumbled. Crumbled.					
Hysunite Acid Dis- charge Hose (Good- year)	3	Inside liner of hose swelled, blistered, very soft, and much more flexible than original sample.					

where the penetration rate was about 2.0 mils per year. Under these severe conditions, a very thin coating of black powder appeared on the metal surface. No pitting occurred.

#### Static Tests of Titanium in Stainless-Steel Containers

Titanium (75A and 6Al-4V) was not attacked at 21 or 74 C during exposures of 9 and 27 days in N2O4 containing 0 to 3.2 percent added water. Formation of pyrophoric compounds did not occur. Several exposed specimens were struck in the absence of N2O4 with a hammer with the only result that of denting the specimens.

#### Stress Corrosion Tests

Three metals, carbon steel, aluminum, and PH15-7Mo (condition RH950) stressed to the yield point were exposed at 49 C to N<sub>2</sub>O<sub>4</sub> containing 0.1 and 1.6 percent water. After 41 days, no cracks were apparent by visual examination. Photomicrographs likewise did not reveal any signs of stress corrosion cracking.

#### Elastomers

Several plastics and types of rubber were exposed to liquid N<sub>2</sub>O<sub>4</sub> at room temperature. Data are shown in Table 4. All but two, Kel-F and Teflon, failed to retain their original properties for more than a few hours. Koroseal was a borderline case, changing appearance and dimensions but becoming stiffer and much stronger after exposure and subsequent air drying. In this manner, all but Kel-F

and Teflon were eliminated for possible use in transporting liquid N2O4 and these two were tested as described below.

#### Dynamic Tests

Two tests were run by circulating commercial N<sub>2</sub>O<sub>4</sub> at 26 to 31 C, 12 to 15 gpm (about 10 ft/sec across metal specimens) in a closed system. Data are shown in Table 5. Average penetration rates for metals in both tests calculated on the basis of the circulation time are shown in Table 6.

Corrosion rates based on the total exposure time, including periods when the pump was not running, were lower. Welded nipples of carbon steel, stainless steel (304), and aluminum through which N.O. returned to the reservoir were cut lengthwise. All welds and nipple interiors were in excellent condition. Stainlesssteel (304) and carbon-steel ells removed from the piping were in excellent condition. The carbon-steel (ASTM, A-285, Grade C) and stainless-steel (304-L) impingement plates kept their original bright finish. The carbon-steel plate showed a corrosion rate of 0.23 mpy. The stainless-steel plate was not affected.

Teflon proved to be the most satisfactory of the plastics tested although it underwent a slight swelling and suffered a reduction in strength. Kel-F also swelled and lost strength as shown in Table 7.

African Blue Asbestos and Teflon Impregnated Asbestos (Palmetto 1330) appeared to be unchanged by exposure in the reservoir. Teflon and Kel-F were only slightly discolored. Koroseal shrunk,

#### TABLE 5—Corrosion Rates of Metals and Non-Metallic Materials in Flowing No.

Location of Specimen In Assembly	Material	Observation And Corr	rosion Rates In MPY*	Observation And Corr	osion Rates In MPY**
Specimen Container	PH 15-7 Mo Stainless 1 Steel 2 3 3 304-L Stainless Steel 4 5 5 6 6 5086 Aluminum 1 1 6 4 4 7 285 Grade C 9 10 11	Rates based on 101 hours con- tinuous circu- lating time 0.04 0.02 0.00 0.00 0.00 0.39 0.26 0.31 0.24 0.23	Rates based on 0.00 total time spec- 0.00 imens were in 0.00 assembly, 20 0.01 days 0.00 0.00 0.00 0.00 0.00 0.00 0.05 0.05 0.07 0.05 0.05	Rates based on 104 hours continuous circulating time 0.00 0.00 0.00 0.00 0.01 0.05 0.72 0.16 0.17 0.62 0.16 0.17 0.62 0.16 0.17 0.62 0.16 0.16 0.17 0.62 0.16	Rates based on total time spec- 0.00 imens were in assembly, 6 0.03 days 0.00 0.15 0.51 0.11 0.13 0.46 0.11
Impingement Holder	Carbon Steel-ASTM 1 A-285 Grade C 304-L Stainless Steel 2	0.23	0.05	0.00	0.00
Non-Metallic Tubes	Kel-F Teflon	Stretched ½" in length, st turned tan in color. R of dynamic test.	welled .025" in diameter, emoved after 2½ hours	Stretched 3/8" in length, so turned tan in color. If of dynamic tests.	welled 0.01" in diameter, Removed after 205 hours
Reservoir Specimens	Koroseal Alathon Polyvinyl Chloride Kel-F Lucoflex Polyvinyl Chloride Teflon Johns-Manville Service Asbestos African Blue Asbestos Teflon Impregnated Asbestos-Palmetto 1330	Shrunk slightly and becar Crumble. Swelled and became soft a No change in size, but slig Swelled and became soft a Discolored and became so Blistered and showed som Good condition.	and flexible. ghtly discolored. and flexible. fter.		

<sup>\*</sup> Run 1; 101 hours of test; recirculating N2O4; 12.5 gallons per minute, 26-31 C temperature range, 7 psig maximum pressure on reservoir, 50 psig average discharge pressure. \*\* Run 2; 104 hours of test; recirculating N2O4; 12.5 gallons per minute, 25-32 C temperature range, 8 psig maximum pressure on reservoir, 50 psig average discharge pressure.

Elbows in Assembly

3—Type 304 Stainless Steel.

2—Carbon Steel.

Welded Nipples in Assembly

1—Carbon Steel.

All elbows remained in original condition and showed no weight loss during 205 hours of dynamic test.

<sup>—</sup>Carbon Steel —Type 304 Stainless Steel —Aluminum (grade not known)

Cross-section specimens from each of the welded nipples were examined and found in good condition after 205 hours of dynamic tests.

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TABLE 6-Corrosion Rates in Flowing Commercial N2O4 At 26-31 C

Appear- ance	Average Corrosion Rate, MPY
Slightly Tarnished	0.33
Bright	0.01
	0.00
	Slightly Tarnished

TABLE 7—Bursting Strength and Bend Tests of Teflon and Kel-F Tubes

•	Teflon, 13	/16 In. OD	Kel-F, % In. C		
	Before	After	Before	After	
Hours Containing N2O4	0 1000+	624 205 690	0 1000+	381.5 2.5 455	
Bend in 21-In. Horizontal Length, Inches Vertical Load, Grams 0.0 136.5 536.5 1036.5	7/16 11/2 41/4 77/8	25/8 37/8 71/2	114 178 4 634	31/2 111/4	

#### TABLE 8-Effect of Teflon on Corrosion of Steel and Aluminum

	SERIES A  3 3/16" x 11 <sup>11</sup> /16"  STAINLESS STEEL 304						SERIES B  4½" x 11½"  STAINLESS STEEL 304L							SERIES C  4½" x 11½"  STAINLESS STEEL 304L					
Container Dia. x Length																			
Material																			
Vol. N2O4, ml	300	300	300	300	300	300	600	600	600	600	600	600	600	600	600	600	600	600	600
H2O, Wt. %	1	1	1	1	1	1	3	3	3	3	3	3	3	1	1	2	2	3	3
Metal Exposed		Carbon Steel (1) Aluminum 5086 Stainless Steel 304L							Carbon Steel(1)										
Metal Area, sq. cm	24.8	24.8	24.8	24.8	24.8	24.8	32.4	33.7	31.4	31.6	35.9	35.9	30.9	34	34	34	34	34	34
Teflon Present	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	Yes	No	Yes	No	Yes	No
Kind Teflon	Garlock		Air Force		Garlock		Air Force		Air Force		Air Force		Gar- lock	Air Force		Air Force		Air Force	
Area Teflon, sq. cm	322		322		322		322		322		322		322	322		322		322	
gm H <sub>2</sub> O/sq. cm metal sq. cm Teflon/gm N <sub>2</sub> O <sub>4</sub>	0.017 0.75	0.017	0.017 0.75	0.017	0.017 0.75	0.017	0.79 0.38	0.76	0.82 0.38	0.81	0.72 0.38	0.72	0.83 0.38	0.25 0.38	0.25	0.50 0.38		0.75 0.38	0.75
Temperature, °C	Room temperature ca. 25 C							74	74	74	74	74	74	46	46	46	46	46	46
Days Exposure	17	17	19	19	14	14	6	6	6	6	10	10	7	7	7	7	7	7	7
Losses, mg 1	11.6 12.0	3.9 3.0	1.5 1.4	1.9 1.9	15.1 17.5	12.4 12.4	1184 1175	113 111	396 402	241 410	11 11	0.4	5 5	31.9 34.8	2.7 1.2	307 273	4.9 4.9	259.8 250.5	2.8 11.5
Avg	11.8	3.5	1.5	1.9	16.3	12.4	1179	112	399	326	11	0.4	5	32.4	2.0	285	4.9	255.2	7.3
Penetration, MPY Avg	1.1	0.3	0.1	0.15	1.7	1.3	221	20.1	240	186	1.08	0.04	0.87	5.1	0.3	44.4	0.75	39.0	1.1

<sup>(1)</sup> Carbon Steel ASTM A285 Grade C.

polyvinyl chloride swelled and Alathon crumbled. Johns-Manville Service Asbestos blistered and showed slight dimensional shrinkage; however, it gave excellent service as flange gaskets.

The canned pump appeared to be unaffected by the 205 hours' service. The wetted portion of the pump was con-structed of 316 stainless steel. The bearings, also wetted with N2O4, were made of graphite. This pump was run with an average suction pressure of about 6 psig and a discharge pressure of about 50 psig. Previously, a standard centrifugal pump was used. It was equipped with the conventional lantern ring packing gland. Three grades of packing, African Blue Asbestos, Teflon cone or chevron rings, and Kel-F chevron rings were used, the latter lubricated with Kel-F 90 grease. In no cases were more than 10 hours running time obtained without total failure of the packing.

#### Effect of Teflon

The presence of Teflon in N<sub>2</sub>O<sub>4</sub> containing water markedly increased the corrosion rate of carbon and stainless steel but did not significantly affect the corrosion of aluminum 5086. Table 8 summarizes the data that lead to this conclusion. As a result of these findings, tests in the Teflon-lined containers were discontinued.

Data in Table 8 are divided into three series, A through C. Series A is a group of tests conducted under mild conditions, 25 C, 1.0 percent water, that showed no significant difference in corrosion rate in presence or absence of Teflon. This led to the conclusion that Teffon was not a complicating factor; however, subsequent tests run at more severe conditions (3 percent H<sub>2</sub>O, 74 C) set forth in this study gave evidence that Teflon was being attacked and the corrosion rate of stainless steel was inordinately high.

Accordingly, six comparative tests were conducted, shown as Series B in Table 8, at 3 percent water, 74 C, on stainless steel, carbon steel, and aluminum. Data from this series show that carbon steel and stainless steel were corroded at rates 10 to 20 times higher in the presence of Teflon than in its absence. The corrosion rates for aluminum were only slightly higher in the presence of Teflon.

In the case of stainless steel, Garlock's Teflon sheet packing showed the same effect as Teflon cut from a container liner. In order to determine how extensive the deleterious effect of Teflon might be, the tests shown in Series C were conducted on carbon steel at an intermediate condition of severity, 1 percent water, 46 C. Data from these comparative tests show that the rates are many times

greater in the presence of Teflon than in its absence.

No attempt was made to determine the route or mechanism through which Teflon products react. One sample of N2O4, after exposure, was analyzed and found to contain less than one ppm fluorine. Further investigation was believed beyond the scope of this study.

#### Conclusions

Corrosion of carbon steel (ASTM A-285, Grade C) and aluminum (5086) was less than 0.5 mil per year in nitrogen tetroxide containing up to 0.2 wt percent water at 74 C, increasing to 50 mils per year at 3.2 wt percent water and 74 C. Negligible corrosion was observed under severe conditions with stainless steel (304-L) and titanium (75A and 6Al-4V) whereas high strength steel (PH15-7Mo) showed losses of 0.5 to 1.0 mil per year. No stress corrosion cracking was observed in tests on carbon steel, high strength steel, or aluminum in nitrogen tetroxide containing 0.1 and 1.6 wt percent water at 49 C. Significant corrosion of stainless steel (304-L) occurred in the presence of Teflon.

Dynamic tests showed no significant corrosion of 304-L and PH15-7Mo stainless steels and average rates of 0.05 mil per year for aluminum and 0.33 mil per year for carbon steel after 205 hours' exposure to commercial nitrogen tetroxide flowing at velocity of 10 fps at 30 C.

Teflon and Kel-F were the most satisfactory non-metals tested. Asbestos-type gaskets gave good service.

#### DISCUSSION

Question by Ralph P. Liberto, 65 Arcade Ave., Amherst, New York:

What was the water solubility in  $N_2O_4$  at -9 C?

Reply by H. F. Scott, Jr.:

Water is soluble in N2O4 to the extent

of 1.6 weight percent at 0 degrees C. We do not have data at -9 C.

Questions by Hugh P. Godard, Aluminium Laboratories Ltd., Kingston, Ont., Canada:

1. What was the water content of the commercial grade nitrogen tetroxide used in this test?

2. What is the specification limit for moisture?

Replies by H. F. Scott, Jr.:

1. 0.004 weight percent.

2. 0.1 weight percent, maximum.

Question by Walter K. Boyd, Battelle Memorial Institute, Columbus, Ohio:

In connection with your studies, did you determine if titanium is sensitive to impact in the presence of N<sub>2</sub>O<sub>4</sub>?

Reply by H. F. Scott, Jr.:

Under a recent government research contract, we have found that commercially pure titanium and titanium alloy 6Al-4V show limited sensitivity to impact, but no propagaton of ignition. The results of this study will be available later this year.

Any discussion of this article not published above will appear in December, 1961 issue.

# Corrosion Measuring Probes for Marine Applications\*

By DAVID ROLLER, WILLARD R. SCOTT, JR., HERMAN S. PREISER and FRANK E. COOK

#### Introduction

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> THE SHIP BUILDING industry has had to contend with external ship hull corrosion for many years. Considerable effort has been expended to eliminate this corrosion problem through the use of protective coatings, better materials, and cathodic protection. The success of this program attests to the general effectiveness of the methods used to evaluate systems under test. However, there continue to be many special problems wherein detailed corrosion data on specified areas of in-terest would be most valuable, but which cannot be obtained by using available test methods.

Hull exteriors have received considerable attention, but much less effort has been expended to detect and eliminate corrosion on the interior surfaces of the hulls. According to Capp and Philibert,<sup>1</sup> corrosion damage seldom occurs on the exterior of ship hulls between dry dock inspection periods to an extent that might endanger the operation of the vessel. However, serious internal corrosion, frequently overlooked, does often occur, resulting in significant damage to the hull and accompanying structure. Tanks, bilges, shell plating, longitudinals, frames and other structural members on the interior of the vessel are sometimes severely attacked. High humidity (moisture), alternate wetting and drying, salt residues, improper design and fabrication techniques, poor choice and combinations of materials, combined with rough usage and sporadic maintenance lead to an environment which is highly corrosive to these components.1

The primary method used to determine the extent of corrosion damage aboard vessels has been visual probing. Ultrasonic thickness testing has also been used with limited success. Because of the time involved and inaccessibility of many critical locations, testing is usually restricted to times when the ship is in port or in drydock. But visual examinations can only qualitatively assess possible corrosion damage, while ultrasonic measurements are not sufficiently sensitive or discriminating for that purpose. Thus serious corrosion damage that can not be easily observed may be over-

looked. Weight loss measurements require the placement of weighed specimens into locations from which they can be removed at intervals for cleaning and

Scott





Roller

Preiser

Cook

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WILLARD R. SCOTT, JR., is presently Technical Director of the Research and Development Division of Magna Products, Inc., Anaheim, California. His work includes studies on the mechanism of corrosion, development of corrosion measuring instrumentation, and development of corrosion preventatives. A member of NACE, ACS, and the Electrochemical Society, he received his PhD from the University of California at Los Angeles in 1950.

HERMAN S. PREISER is president of Chemionics Engineering Laboratories, Inc., Bala-Cynwyd, Pennsylvania. He was formerly a consulting corrosion engineer in charge of cathodic protection for the Research and Development Division of the U. S. Navy Bureau of Ships. He has a BS degree from Webb Institute (1949). Mr. Preiser has been active in NACE affairs since 1948 and was Technical Program Committee Chairman for the 1959 Northeast Regional Meeting. He has contributed profusely fo the corrosion literature and he holds several patents related to shipboard cathodic protection systems.

FRANK E COOK is a Supervising Materials Engineer with the Navy Dept., Bureau of Ships, Washington, D. C. He received a BS in Chemistry from Roanoke College and an MS in chemical engineering from Ohio State University. He is a member of NACE, ACS and ASNE.

#### Abstract

Abstract

This paper describes the design, fabrication and preliminary testing of several types of corrosion measuring probes developed for use on maritime vessels. The probes are part of a system utilizing the electrical resistance method for continuously monitoring corrosion during actual operation. One type of probe to be described is intended for monitoring corrosion on either the exterior surface of the hull or interior structural members in large compartment. Another probe has been developed for measuring condenser tube inlet (tube end) corrosion. A third probe has been developed for measuring corrosion in crevices and pipe lines. Both laboratory and simulated service testing has been carried out. Results of these tests and the effectiveness of the probes in measuring corrosive conditions on ships are discussed.

2.4.2

reweighing. The mechanics are difficult to perform at sea; corrosive areas are usually remotely located, making repeated access difficult. Also, there is no way of knowing during a test inter-val at what rate the environment is corroding the structure, or what changes may be taking place.

Thus, for one reason or another, corrosion measurement and control are inherently difficult aboard ship, and especially when the ship is under way. In order to make the task simpler, and hence to promote more efficient and

complete control of corrosion, easily used and remote reading corrosion measuring methods are highly desirable. One such method is the electrical resistance method, around which the probes described herein have been designed.

The electrical resistance method for measuring corrosion has been adequately described in the literature.2, 3, 4, 5, 6, 7 This method has certain advantages of particular interest to shipboard corrosion problems. These may be summarized as

- 1. Test specimens may be made in a variety of sizes and shapes to fit into almost any location.
- 2. The method inherently measures only the amount of virgin metal present. Readout is independent of any protective coatings, scale, dirt, fouling, or other protective systems, all of which have low conductivity in comparison with the metal specimen.
- 3. Readings may be telemetered to any location without removing the specimen from the environment.
- 4. Direct measurements in micro-inches loss of metal thickness are pos-

<sup>★</sup>Submitted for publication January 16, 1921. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, New York, March 13-17, 1961.

The advantages of the electrical resistance method for marine applications certainly outweigh a few disadvantages which sometimes arise. Severe pitting attack may cause discrepancies to arise in any comparison of the electrical re-

Figure 1-Interior hull probe.

sistance data with weight loss data (if the latter is available). This problem can be reduced to any desired extent by suitable design of the probe and by proper interpretation of the data after visual examination of the measuring element. Resistance data may occasionally be in error due to failure of the reference element's protective coating or due to long-term stress relief. These problems are not expected to occur to any appreciable extent in the shipboard environment, however.

In view of the valuable potential contribution of the resistance method to shipboard corrosion technology, a number of special probes were developed under the auspices of the Bureau of Ships, U. S. Navy Department. The bulk of this paper describes the design, construction, and preliminary testing of these probes.

Three different types of probes were developed under this program. One type is designated as a "hull probe," of which two styles were built. The second type of probe developed is designated as a condenser tube probe," while the third is referred to as a "disc probe." The significance of these designations will be apparent from the discussion.

#### **Hull Probe**

Hull probes were designed to be independent of the end use application. Each unit consisted of a metallic specimen attached to a base plate by means of an epoxy resin insulation layer. The metallic specimen comprised both the measuring and reference resistance elements and associated electrical taps fabricated from a single piece of metal. All the specimen except the measuring element was overlayed with reinforced plastic. Thus the probe structure resembled a sandwich of alternate layers of metal and plastic. This construction provided a rigid and adherent structure which could withstand severe environmental conditions.

It was also desirable that the measuring element of this type of probe have possible use in checking effectiveness of coating systems under actual service conditions. To accomplish this, the measuring element had to be reasonably rugged in order to withstand sandblasting and scraping. The performance, including sensitivity and reliability of the probe, could not be greatly affected by the application of protective systems. The probe's measuring element also had to be large enough to provide a representative sampling of corrosion being experienced on adjacent metal surfaces of the hull. Long exposure periods re-quired that the probes operate over significant time periods without break-down or loss of the measuring element through excessive corrosion. The electrical leads were attached to the metallic sensing elment just prior to the laminating process and were carried away from the unit in a suitable cable. The cable was potted securely into the probe structure to prevent water from contacting the connections. Probes of many different configurations could be fabricated using this general design approach. For example, the general method could be applied to very large probes in which the measuring element would measure several feet in one or both dimensions. Maximum dimensions are limited only by the size of equipment available to perform the lamination.

Two general shapes of hull probes suitable for use in connection with ship corrosion were developed. One was rectangular and the other was round. The rectangular hull probe, which is shown in Figure 1, is intended for use on the walls of interior spaces such as fuel tanks, ballast tanks, voids, etc. To mount the probe, four bolt holes were to be provided at the four corners of the rectangular base plate. A pressure fitting can be provided on the end of the cable for use when the probe is mounted at depths below the water line. This fitting passes through a packing gland mounted through the hull or bulkhead. The connector thus may be located on the open side of the structure.

Circular-shaped probes, shown in Figure 2, were constructed for use on the exterior of ship hulls. The mounting plate is the same diameter (13.5 inches) as is one type of standardized anode unit currently used for cathodic protection on ship hulls. The total thickness of the probe is about a half-inch. The circumference of the probe is beveled to assist in obtaining smooth flow over the measuring element. Six bolt holes are available for mounting the round probe either onto the outside of the hull or flush with the hull surface in a depression. The electric cable containing the leads can exit either from the probe edge in a direction parallel to the plane of the probe or via a stuffing tube passing through the hull directly beneath the probe.

#### Testing and Evaluation of Hull Probes

A number of tests were made during the early part of the work to determine the general suitability of the steel-toepoxy laminates in contact with aerated sea water. One such test consisted of submerging the specimen a few inches below the surface of sea water. In another type of test, sea water was pumped through an orifice in such a way that the water impinged on the specimen surface at various angles. The pumping rate was about ten gallons per minute and the velocity of impingement was about five feet per second. Figure 3 is a photograph which shows this type of test in operation.

During two weeks of exposure to the quiescent submergence test, some corrosion occurred over the entire surface of the exposed steel. In some cases slight undercutting of the edges of the metal was observed. This undercutting was associated with inadequate bonding between the metal and the plastic before the technique had been worked out com-

Normally, the high velocity sea water impingement test was carried out for seven days. During this time a hard black layer of oxide developed over most of the surface. Relatively few bright areas were left where metal was actively

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CORROSION MEASURING PROBES FOR MARINE APPLICATIONS

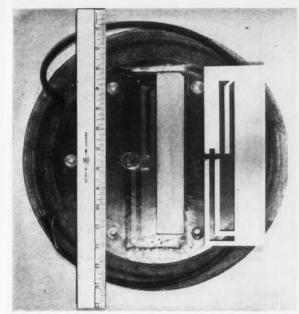


Figure 3—Sea water impingement test stand.

Figure 2—Exterior hull probe with additional sensing element shown prior to casting.

being corroded. No damage was normally observed to the basic structure of the specimens during these tests. No detectable undercutting of the metal layer occurred after suitable bonding techniques had been perfected.

Other tests were undertaken to simulate different conditions to be encountered in marine applications. The primary purpose of the tests was to determine the ability of the laminations to maintain their physical characteristics under service operating conditions. In one set of tests, a tank was used to subject specimens to high velocity sea water by placing them on the face of a circular plate which was rotated at high speed under water by a motor. As shown in Figure 4, the tank was baffled and was quite large compared to the size of the specimen.

Circular discs were made up with several types of probe configurations representative of those types being considered for the exterior hull probe. The perimenter velocity of the plate was about 50 knots and the average velocity of the specimen measuring elements located half-way out on the radius of the plate was of the order of 25 knots.

The temperature of the sea water within the tank varied between 60 F and 110 F during the tests. Heating of the sea water was not considered a problem, however. The higher water temperature resulted in a more severe environmental test. The lower solubility of oxygen at the higher temperature did not markedly affect corrosion rates, presumably be-cause the high degree of turbulence always entrained excess air.

Testing on the high speed disc was carried out over a period of 30 days. The average metal loss on the various exposed areas appeared to be approximately one-half of the original thickness and was non-uniform. No electrical

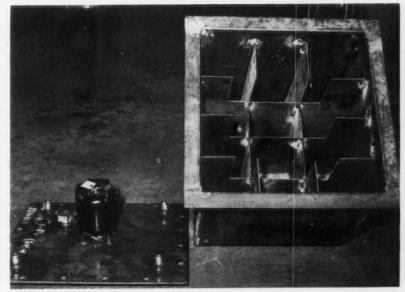


Figure 4-High velocity sea water test tank.

measurements were made on the measuring elements. Visual inspection of the plastic lamination material over and under and at the edges of the measuring elements, made during and after the test, revealed no detectable deterioration of the original condition of the plastic. Thus no problem with the type of plastic selected and the fabrication method should be expected in actual use.

During the 30-day test period described above, three rectangular hull probes having a sensing element geometry similar to that finally selected, and laminated by the same materials and meth-ods used for the spinning disc, were exposed in the sea water of the test tank. These probes were wired for elec-

trical resistance measurements of corrosion. Each probe was located at a different depth in the tank in order to simulate corrosion under different conditions of oxygen supply. Probe No. 1 was placed in a vertical position on the bot-tom of the tank. Probe No. 3 was halfsubmerged at the air-water interface. The previously described rotating circular plate agitated the sea water vigorously. Corrosion was measured on each of the three probes at intervals during the test, using an electrical resistance corrosion measuring device. Figure 5 is a plot of the electrical instrument readings on the three probes during the test. As expected, the corrosion rates increased as the location of the probe

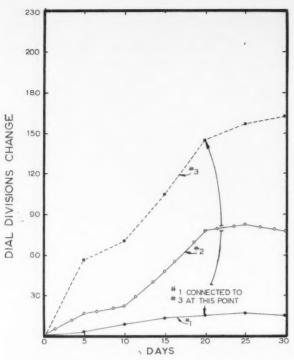


Figure 6—Comparative corrosion of SAE 1010 and HY 80 steels in sea water.

Figure 5—Sea water corrosion test of three mild steel hull probes.

approached the air-water interface. The slopes of the curves indicate that the measuring element thickness which was chosen for testing (0.02 inches) would be expected to be usable for about one year under these conditions.

The above tests were carried out on probes in which the measuring elements were made from commercial mild steel rolled sheet. Ordinary steel was used for all preliminary development and test work because of its immediate availability in thin sheet form. Other steels might have been specified for test because of their use in ship hulls. Nevertheless, it was felt that the ability of these probe elements to convey corrosion information electrically could be demonstrated completely by means of prototypes made from mild steel.

A rectangular hull probe was fabricated from HY 80 steel to confirm the belief that no fabrication problems would be encountered with special steel, and to see how the corrosion rate of high yield steel would compare to mild steel under the same corrosion test conditions. A sheet approximately 0.02 inch thick was prepared from 0.625 inch plate by grinding and chemical milling from one side only to preserve the original surface condition on the opposite side. A rectangular probe was then fabricated from this with the original untreated alloy surface exposed. The type of probe used is shown in Figure 1. The electrical response of this probe was compared to that of an identical probe made from ordinary mild steel rolled sheet in a test set-up using continuously renewed sea water. The test conditions were as follows: Sea water was pumped out of the surface of Long Beach (California) Harbor at the rate of about 10 gallons per minute. The water was discharged into an open top tank having a capacity of 25 gallons. Discharge from the tank was through a ½-inch ID pipe. The rectangular probes were placed near the inlet pipe so that the flow across the probe surface was rapid and turbulent.

Electrical corrosion data are shown in Figure 6. It is apparent that the corrosion behavior of the high yield steel surface as measured electrically is very similar to that of the rolled mild steel under these conditions. The agreement is well within that to be expected from two probes made from exactly the same alloy.

#### Condenser Tube Probe

Corrosion of condenser tubes in heat exchangers is often a serious problem. If the tubes corrode and perforation occurs, then the fluid in the tubes contaminates the fluid in the shell, producing an intolerable situation. Without means of measuring this damage, it is often necessary to over-design by using better and more expensive alloys than actually needed.

Methods of reducing corrosion of tube ends have been under investigation intermittently for some time. Cathodic protection has been utilized with some success. This effort has been hampered by the lack of any means of measuring the effect of mitigation procedures over short time intervals without shutting down the condenser for inspection. The probe to be described here was developed to fill this need.

The desired probe had to measure the corrosion rate of the condenser tube

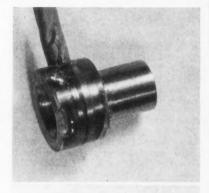




Figure 7—Two views of prototype condenser tube probe.

at those points where corrosion damage was most serious. In most cases, corrosion occurs first at the lip of the tube where the tube end is flared into the tube sheet. Devlopment of a probe which would continuously measure this particular corrosion attack, and, by so doing, forewarn the user, was desired. Through its use the effects of variable such as velocity, temperature, water composition and cathodic protection on different alloys could be determined, simply and directly.

By suitable modifications, such a probe could also be used to detect and measure vater.

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Figure 8—Test apparatus for evaluating tube probes in simulated one tube heat exchanger,

corrosion at pipe inlets, convergent pipe sections, and at tank exits where sudden increases in liquid flow rates often cause excessive corrosion. It is also possible that the probes can be used to monitor the corrosiveness of solids and gases flowing in tubes. Sudden con-strictions (swedges) in flow systems can often be problem areas where the amount of corrosion occurring can be quite serious.

#### Design and Construction

The approach taken was to design a probe which could be fabricated independently and subsequently installed in the inlet of a condenser tube. A prototype condenser tube probe as finally built, is shown in Figure 7. The measuring element of this probe consists of a small split ring with the inside diameter shaped as closely as possible to the shape of the flared inlet end of a condenser tube. This split ring is cast into epoxy resin using a suitable die. A shouldered metal sleeve is cast into the assembly to serve as a mounting tube. The outside of this mounting tube fits inside of the end of the condenser tube to a depth of about 11/2 inches. The mounting tube is made of the same alloy as the tube into which it is placed to avoid galvanic couples. The inside trailing edge of the metal sleeve is beveled to allow a smooth transition of water from the probe into the condenser tube. Units built to date fit 5/8 inch OD x 18 gauge tubing. Sizes to fit other tubing could be made using different dies.

In order to insure a good, permanent electrical contact between the mounting sleeve of the tube probe insert and the condenser tube, the two metal surfaces must fit smoothly and closely together. This presented several problems. First, the inside diameter of commercially available condenser tubing is subject to considerable variation (within limits), as only the OD is held to close tolerance. Furthermore, when a tube is flared into the tube sheet, the inside surface of the tube immediately downstream

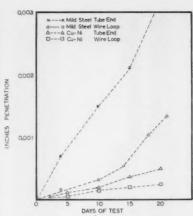
from the flare is considerably distorted. Thus, without doing something to the inside of the tube ends, there was little hope of getting the necessary fit. For this reason, it was decided to ream out the inside of any tube into which a probe was to be fitted. The amount of metal that must be removed is quite small, however. A special reaming tool was designed and built for this purpose. No undesirable effects or mounting problems were anticipated or encountered.

The electrical connection to the measuring element unit is made by means of a suitably protected cable which passes through the water in the header and terminates in a pressure bushing and receptacle accessible from the outside. The bushing is usually located on a flat, access-hole cover.

The reference resistance element, which furnishes temperature and voltage compensation, was designed as a separate unit, and resembles a thermometer well. This arrangement greatly reduced the over-all size and complexity of the main part of the probe (i.e., that which fits into the tube end). The reference element unit terminates in the same type of pressure feed-through as is used with the measuring elements, and mounts alongside the measuring element receptacle on an access plate. Readings are made by plugging the externally located corrosion probes into the two electrical receptacles. If desired, cabling may be utilized so that the instrument may be located at some distance from the heat exchanger.

#### Testing and Evaluation of Tube Probes

Since the probe would be installed in the end of the tube, possible interac-tions of the probe and its environment were considered. These included disturbance of the normal flow pattern at surrounding tube inlets, and the effect of decreasing the condenser tube inlet diameter. It was concluded that the flow pattern was no problem, but that the corrosion measured will be slightly more severe than that in the normal con-



-Comparative corrosion data from simulated condenser tube test.

denser tube because of the higher fluid velocity through the probe.

The tube probe was tested for qualitative sensitivity to corrosion by partially dissolving the measuring element with nitric acid. The test was performed by dropping nitric acid solution onto a restricted portion of the circumference of the ring-shaped element. Localized attack was used to simulate the usual form of corrosion observed in actual tube ends. The test showed that sensitive electrical measurements of this type of corosion could be made with this probe using available instrumentation.

Simulated service testing in sea water was carried out in a special apparatus in which conditions resembled those in a heat exchanger unit, as shown in Figure 8. With the pump used, the fluid velocity in the throat of the condenser tube was about 20 feet per second.

A prototype condenser tube probe with a measuring element fabricated of mild steel was the first to be tested in this apparatus. The probe was inserted into the end of the condenser tube with the electrical leads emerging from the pipe through a packing gland. Readings were made by means of an electrical resistance corrosion measuring device connected to the leads on the outside. For comparison, a standard type wire loop probe\* with a mild steel sensing element was mounted with the element inside of the downstream end of the condenser tube in which the tube-end probe was inserted. The flow velocity at each of these test probes was thus about the same.

The upper two curves of Figure 9 show the results of this test. Note that the probe in the tube end configuration corroded at three times the rate of the wire loop. If these slopes were to persist, the loss per year would be 0.020inch on the wire probe and 0.060-inch on the tube end probe. From this test it was clear that the configuration of measuring element chosen was indeed capable of measuring corrosion localized

at the end of the tube.

In another similar test, a prototype

<sup>&</sup>lt;sup>6</sup>Crest Instruments, Corrosion Measuring Probe Model 203Z-W40.

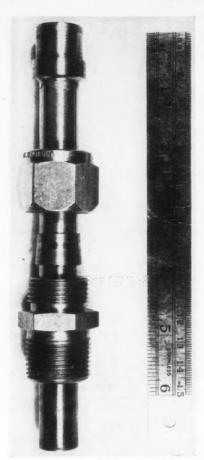


Figure 10—View of disc probe showing Lenz adjustable fitting.

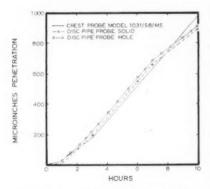


Figure 11—Comparative corrosion data of different disc probe sensing elements.

tube probe with a 70-30 copper-nickel element and a 70-30 copper-nickel wire-loop probe were exposed under similar flow conditions. The results are shown in the lower two curves of Figure 9. Note that the copper-nickel tube insert corroded at a rate that was only one-sixth that of the mild steel insert. The wire probe corroded about half as much as the tube insert in this case. No under-cutting at metal-to-plastic interfaces was noted on the tube insert, and no crevice attack was noted where the probe mount-

ing sleeve had been in contact with the inside of the condenser tube itself. Thus the overall design and construction appeared entirely satisfactory from a structural point of view.

#### Disc Probe

Another probe design was needed for use in locations where openings were small or where intervening structures and ship components prevented easy access. The probe would be capable of detecting and measuring corrosive action behind bulkhead insulation, in pipes and pumps, in voids between tanks and in other relatively inaccessable environments. A general purpose probe which could be used under the broad conditions implied by these application areas appeared to be useful.

Design and Construction of Disc Probe

This disc probe was designed to provide a relatively small flat measuring element which could be inserted into confined locations. The measuring element was designed as a circular disc of exposed metal, mounted in the end of a tube with the exposed surface perpendicular to the axis of the tube. The measuring element size could be varied between broad limits if desired. However, to permit inserting the probes easily into small pipes and voids, the diameter of the measuring element was fixed in initial efforts at ½-inch. For this diameter of element the mounting tube is 5%-inch OD.

The measuring element and the reference element of the design chosen were cut from a single piece of metal. The sensing element structure with electrical taps was then bent into the proper spatial configuration to fit into the mounting tube, in which it is potted with epoxy resin. The probe casing could have been made of any metal or suitable plastic. A stainless steel tube was selected for durability and hardness. The tube is electrically isolated from the probe. A tube length of six inches was selected for preliminary evaluation.

By utilizing a suitable mounting system, the length of insertion of the tube into the environment can be adjusted from the outside. An off-the-shelf mounting-bushing (Lenz Co., Dayton, Ohio) was found to be satisfactory to provide this type of adjustment. The reusable Lenz fitting consists of a bushing through which the probe tube is inserted, an O-ring seal, and a tapered, split-ring locking device and nut. A photograph of the probe and the Lenz fitting is shown in Figure 10.

#### **Evaluation of Disc Probe**

Because of the unusual shape of the sensing element used in the disc probe, there was a question of whether the current used to energize the probe would distribute itself uniformly from the relatively small contacts with the lead wires. To investigate this question, a mild steel sensing element was made with a solid circular disc and another was made with a disc having a ½-inch hole in the center of the circle. These two probes were then exposed to dilute nitric acid

to provide uniform etching for comparative results. In addition, a standard electrical resistance probe was exposed to the solution at the same time. The behavior of the latter type of probe in this environment was known from past experience.

The results of this test are shown in Figure 11. Note that the solid circular measuring element gave essentially the same response as the one with the hole. Also, these gave corrosion rates which were close to that measured by a standard probe within the usual limits of reproducibility of corrosion measurement.

A field test of this type of probe was made in which a mild steel measuring element was installed in the suction side of a pump supplying sea water. The velocity of sea water was about two feet per second. The measuring element was originally ten mils thick. With a measuring element this thick, the electrical resistance corrosion measuring device is sensitive to thickness changes of about five microinches metal loss. Under these conditions the probe lost an average of 140 microinches per day over the 20 day test period. This corresponded to a corrosion rate of 58 mils per year. Though no comparative corrosion data is known, the corrosion rate is considered to be realistic, considering that sea water flowing continuously past the mild steel measuring element. No difficulties were experienced with the probe's operation.

#### Conclusion

Corrosion measuring probes have been developed for a number of marine applications. The probes utilize the electrical resistance method to detect and continuously measure corrosion under actual operating conditions.

One probe has been developed for use on exterior ship hulls; another similar type for interior hull sections, tanks bilges, holds, structural members and other relatively large areas; another for installation in pipes, and small voids; and another, for installation at the entrance to condenser tubes within heat exchangers, and for use at pipe entrances from tanks or larger pipes.

The operational characteristics for each type of probe have been studied in both laboratory and simulated service tests. Auxiliary instrumentation has been used where necessary. Results of these tests showed that the probes would operate reliably and accurately. Measurements made of corrosion were consistent with available information on marine corrosion.

Based on the results of this program there would seem to be a large number of uses for these probes. Since they can be used to monitor corrosion continuously, the effectiveness of various types of corrosion preventives such as cathodic protection, paints, greases, and chemicals can be assessed as a function of the environment. New corrosion preventives can be studied using these probes as measuring tools. Other applications for these probes are possible, such as measuring cavitation corrosion, evaluating new materials of construction,

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and studying the effects of real environments on materials.

Acknowledgments

The technical work described herein was sponsored by the Department of the Navy, Bureau of Ships, under Contract NObs 77071 (1737). The conclusions made herein are those of the authors and not necessarily those of the United States Navy or the Department of Defense.

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DISCUSSION

Question by Joseph Z. Lichtman, Naval Material Laboratory, New York Naval Shipyard, Brooklyn, New York:

In some situations it was indicated that it was necessary or desirable to locate the temperature reference element at some distance from the detector probe. Unless temperature measurements are taken to determine that the temperatures are the same, would there be an appreciable error in the corrosion measurement and how would it be temperature dependent?

Reply by the authors:

Because temperature changes affect the electrical resistance of both the measuring and reference elements, it is necessary that the two probe elements be at the same temperature or at a constant temperature difference. As long as temperature changes in the environment affect the resistance of both measuring and reference elements in the same manner, the resistance ratio (and therefore the electrical resistance corrosion meter reading) is independent of the temperature of the environment.

CORROSION MEASURING PROBES FOR MARINE APPLICATIONS

Temperature measurements may be taken to ascertain that both measuring and reference elements are in the same temperature environment. Errors in corrosion measurements due to fluctuating temperatures which are not compensated for by the reference element may be appreciable and will depend upon the magnitude of the temperature difference, the metal, and other factors. However, with rapidly fluctuating temperatures where the reference element may not follow the temperatures changes of the measuring element exactly, only the precision of individual measurements may be reduced. The accuracy of average corrosion rates calculated from a series of measurements usually is not affected.

Experimentally, the rapid transference of a 4 mil mild steel probe from dis-tilled water at 75 F to distilled water at 80 F and back again will create an error of the order of 5 microinches. After the reference element probe reached equilibrium, the reading had returned to its correct value. Thus, errors due to temperature fluctuations are temporary and

are noncumulative.

Questions by Fred W. Fink, Battelle Memorial Institute, Columbus, Ohio:

1. What is the velocity in your experimental condenser tube in ft/min?

2. How do you explain your statement on no change in resistance with load with the known behavior of strain gauges?

Repiles by the authors:

1. The velocity of sea water in the throat of the condenser tube probe mounted in our experimental laboratory condenser tube during all tests was about 1200 feet per minute.

2. Probes described in the paper are structurally designed to be used to avoid transmitting stresses from the structure to the probe in marine environments. If either the measuring or reference elements were mechanically stressed, there would be a change in the electrical resistance dependent on the metal and the level of stress applied. Strain gauges are designed to experience far greater strains (e.g., physical deformation) than occurs on corrosion probes.

Question by Preston W. Hill, 2828 Junipero Ave., Long Beach, California:

Would not the reference element compensate for stress variation as well as temperature?

Reply by the authors:

Probes described in the paper utilize a reference element in series with the sensing element to permit the electrical resistance corrosion device to measure the electrical resistance ratio of the current used to energize the probe and, also, are independent of the temperature of the environment. The probes described would also compensate to a large degree for stress, provided that both sensing elements experience the same stress. The standard types of probes have not been designed specifically with this in mind, however.

Any discussion of this article not published above will appear in December, 1961 issue.

## Stress Corrosion Cracking of Admiralty Exchanger Tubes In Reformer Service\*

By K. R. WALSTON\*

#### Introduction

THE PHENOMENON of stress corrosion cracking of brass in contact with ammonia is not new. But despite the experience gained by corrosion engineers, new cases continue to show up.

Four factors are thought to be necessary for this type of corrosion to occur. One factor is a still undefined tensile stress which may be residual, may be due to thermal expansion, or due to other mechanisms so elusive as to defeat any attempt to eliminate completely stress corrosion by heat treating. Ammonia, air and moisture also are all required before stress cracking can occur. In fact, many of the difficulties have occurred following satisfactory onstream experiences in ammonia contaminated environments after the tubes were exposed to the air and moisture in the atmosphere during downtime.

Practically all refiners use ammonia for pH control to reduce corrosion in the overhead streams from crude stills and light hydrocarbon fractionating units. This seeming anomaly is generally attributed to the inhibitive effect of the omnipresent hydrogen sulfide. Cases of stress corrosion in crude unit condensers are indeed rare, and few corrosion engineers have any qualms about recommending ammonia for pH control in admiralty exchangers in crude units, cat crackers, gas plants, etc.

#### Discussion

Figure 1 shows admiralty tubes recently removed from a reactor effluent cooler on a large platinum reforming unit. This unit had been down for turnaround and was being purged and tested for tightness. When water was turned into the tube side of this exchanger, water was observed coming from the shell drains. A subsequent test indicated that over 25 percent of the tubes would not pass a hydrostatic test. Metallurgical examination revealed the branched cracks typical of stress corrosion, progressing from the effluent side to the water side. The slightest bending of the tube was sufficient to open up additional cracks in the tubes.

The unit had not been inspected be-

#### Abstract

Abstract

Stress corrosion cracking occurred unexpectedly on admiralty exchanger tubes removed from a reactor effluent cooler on a platinum reforming unit. It was found that ammonia was liberated when this liquid came in contact with brass. Strong ammonia concentrations gathered during downtime, causing the ensuing stress corrosion cracking. A contributing factor was the lack of offsetting inhibition resulting from an abnormally low sulfur content in the stream. Water washing of all bundles in similar service was recommended as a countermeasure to prevent this type of stress corrosion cracking.

3.5.8, 8.4.3, 6.3.6

cause no corrosion problems had developed in previous inspections and the bundle was functioning satisfactorily when the unit came down. Little or no difficulties had been experienced with similar exchangers on two other units.

Ammonium chloride was known to be present and thus a likely cause of the ensuing corrosion. Normally, however, NH<sub>4</sub>Cl will result in general rather than stress corrosion. Laboratory tests made by introducing brass filings to an ammonium chloride solution demonstrated that appreciable quantities of ammonia could be liberated. This confirmed theoretical predictions that the corrosion of brass by ammonium chloride would result in the liberation of free ammonia.

During the operation of the unit, corrosion was minor and any ammonia formed was swept along with the hydrocarbon stream and not permitted to concentrate. During downtime, however, the corrosion continued. Stagnant conditions caused the ammonia to be trapped in the

exchanger shell and to concentrate in the vapor space. This accounts for the strong ammonia smell reported by workmen when the exchanger was opened. The exchangers had been blanketed with inert gas during the turnaround. This gas contained moisture, carbon dioxide, and possibly small quantities of carbon monoxide and oxygen. It is also probable that some accidental leakage of air inward during blinding and turnaround work was responsible for the oxygen known to be required for stress corrosion cracking.

Another important factor in this case history is the apparent lack of any inhibitive action by the hydrogen sulfide normally present in most units. This was a well desulfurized stream and contained only 5 to 20 parts per million of sulfur. Accurate figures are not available, but this sulfur level probably is not sufficient to provide inhibition. It is also possible that even if adequate sulfide were present during operation it might not provide adequate protection during the turnaround period.

#### Corrective Measures

To prevent future occurrence of this cracking, the practice has been adopted of water washing all bundles in similar service with warm water immediately after shutdown to remove any deposits on the tubes. As an added precaution, the tubes should be blanketed with water or inert gas, preferably nitrogen, during the downtime.

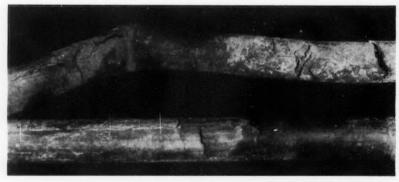


Figure 1—Stress corrosion cracking in admiralty tubes from reformer effluent exchanger.

\* Submitted for publication December 7, 1961. American Oil Company, Whiting, Indiana.

#### **Technical Papers on Corrosion Welcomed**

Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.

# **A New Test for Estimating Soil Corrosivity** Based on Investigation Of Metal Highway Culverts\*

By R. F. STRATFULL\*

#### Introduction

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THERE ARE many reports in the literature which describe various test methods for estimating relative soil corrosivity.1-9 Generally these tests have been based upon a relationship between the rate of corrosion of steel and some measurable characteristic of the soil such as the hydrogen-ion concentration (expressed as pH), the electrical conductivity, the current flow between electrodes, etc.

In 1939 Logan and Koenig<sup>10</sup> compared results of several test methods and found that all were useful, although some tests were more accurate than others. They concluded that no single property determination could accurately correlate the relative corrosivity of all of the soils found in the United States.

In a recently published paper,11 a new test method was described for estimating the corrosion rate of metal culverts used to drain waters beneath highways. Although not reported in detail in Reference 11, a comparison was made between the new culvert test method and the extensive data reported by the National Bureau of Standards on underground corrosion.12

The degree of correlation was a means of checking the significance of the new culvert test method by comparing the results with independently acquired data.

Since a good statistical correlation was obtained between the culvert test method and the published NBS results of the underground studies throughout the USA. this new test method is now being used by the California Division of Highways for evaluating the relative corrosivity of soils for culvert and pipeline installa-

#### **Estimating Corrosion Rate**

The new test method estimates relative soil corrosivity by combining the relative influences of the hydrogen-ion concentration (pH) and the minimum resistivity of the soil. It establishes rela-tive soil corrosivity by plotting these combined values on the chart shown in Figure 1, and indicates soil corrosivity in terms of the corrosion rate of steel buried in similar soils as reported by the National Bureau of Standards. 12

As will be noted in Figure 1, the underground corrosion rate in alkaline soils (pH greater than 7.0) is influenced much more by resistivity than by pH. In acid

#### Abstract

Abstract

Corrosion rates of several thousand metal highway culverts buried in California soils were studied with respect to soil resistivity and pH. From this relationship a new test method was derived to estimate soil corrosivity. Statistical analysis was used to compare the accuracy of this method of estimating soil corrosivity with other known methods. It was found that within limits this new test method was a more reliable indicator of relative soil corrosivity than any of the other investigated methods. It was thought, though, that this method might not prove so effective in predicting corrosion for long pipe lines nor for estimating soil corrosivity in certain geographical areas.

4.5.3

soils (pH less than 7.0), the corrosion rate is controlled by the combined influence of pH and the resistivity of the

Figure 1 is a graphical solution of the original metal culvert corrosion rate survey data, which has been equated to underground corrosion rates. A satisfactory equation which can properly in-corporate the non-linear variables has not been determined.

As indicated in Figure 1, when the pH is constant, the corrosion rate decreases with increasing resistivity. Also, when the minimum soil resistivity is constant, the corrosion rate increases as the soil becomes more acidic (pH numbers become smaller). Since data have been rather limited in establishing the curves in several areas in Figure 1, some minor modifications may be anticipated as further information is accumulated and

The correlation and direct relationship between pitting and the weight loss of steel in the soils shown in Figure 1 was determined by a mathematical analysis of published NBS test data.12

#### pH or Hydrogen-ion Concentration

The pH solution has been used previously in estimating the corrosion rate of steel in soils or solutions.13,14 With other variables held constant, the corrosion rate of iron increases as the solution becomes more acidic. 15, 16 Also, as a single factor determination, the total acidity of an acid soil is a more dependable indicator of its aggressiveness,17 than is the pH. The feasibility of using the total acidity instead of the pH value of a soil was not determined in this study as the pH value was of primary interest; however, future studies are contemplated.

In this study the pH value was deter-mined by means of an electrometric method which included the simultaneous use of a glass and a calomel electrode.

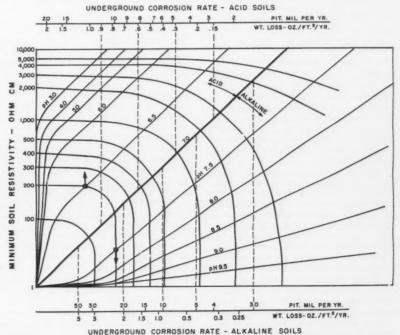


Figure 1—Chart for estimating corrosion rate of steel pipe. Example 1: with pH of 6.5 and resistivity of 200 ohm cm, the underground pipe loss is about 1.0 oz/sq ft/yr and the pitting rate about 0.013 ipy. Example 2: with pH of 7.5 and resistivity of 200 ohm cm, the underground pipe loss is about 2.2 oz; sq ft/yr and the pitting rate is about 0.022 ipy.

<sup>★</sup> Submitted for publication April 3, 1961. A paper presented at a meeting of the Western Region. National Association of Corrosion Engi-neers, San Francisco, California, October 6-7, 1960.

<sup>\*</sup> Corrosion engineer, California Division of High-ways, Materials and Research Department, Sac-ramento, California.

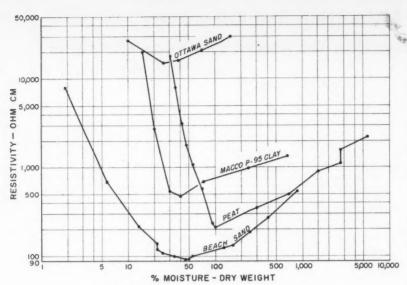


Figure 2—Moisture content plotted against resistivity of soils.

As observed in this investigation and by others, 18 colorimetric methods for determining the pH of unknown solutions gave erratic results and were not used. This behavior was due to the excessive turbidity of some of the solutions which masked the end points.

The pH measurements of the soil solutions generally were obtained by mixing 1 part of soil to 1 part of distilled water by volume in a glass beaker or waxed paper cup, inserting the pH electrodes and recording the resulting values. There is no absolute or constant proportion of water to soil to be mixed for obtaining the pH value, as it has been reported that ratios of 1 part soil to 5 parts water have been used when the soil is high in organic content.<sup>12</sup>

#### Resistivity

When other environmental conditions are equal, the rate of corrosion of steel has been shown<sup>15</sup> to vary with the electrical resistance of the electrolyte or soil. Also, the rate of corrosion of steel, which is exposed to a soil of a low electrical resistance, is more pronounced than that found in a soil of high electrical resistance. <sup>12</sup>

Because of this relationship between low soil resistivity and rapid corrosion, the resistivity of an electrolyte has been extensively used as an indicator of relative corrosivity. The resistivity of a soil is a variable 12,13 that depends upon moisture content, compaction, temperature, salt content and other minor factors. Therefore, the comparison of resistivity characteristics between various soils requires a standardized test method.

As shown in Figure 2, the measured resistivity of soils will decrease to a minimum value with the addition of distilled water. This is a characteristic of all soils. With the addition of more water, the soil solution with its contained salts becomes diluted in respect to free ions and the resistivity increases. In this new test

method, the resistivity value which is utilized is the minimum value obtainable under any moisture content. Generally, the minimum value of soil resistivity was measured when the soil was saturated with moisture and the mixture was generally in the form of a semi-liquid or slurry. Obviously, when a soil is in the form of a slurry, it cannot be compacted; therefore the effect of the compaction variable on the resistivity measurements can be disregarded.

Since the published12 National Bureau of Standards soil resistivity data are based on soils saturated with water, their values of soil resistivity approach those utilized in this new test method and as such appear to be generally interchangeable. A detailed description of the various methods used for the measurement of soil resistivity is given in Reference 12. In this test method the soil was mixed with distilled water, placed in a soil resistivity box, and the resistivity was obtained by means of an alternating current instrument. Then the soil was removed, rewetted, and replaced in the soil resistivity box until the continuing resistivity measurements indicated that the minimum resistivity of the soil had been measured.

It is apparent that the minimum resistivity of a soil would rarely duplicate that found in the natural condition. It is also obvious that the resistivity of a soil measured in its natural condition may be difficult to reproduce, as the moisture content is a controlling factor. This is shown by the curve for the beach sand in Figure 2. Depending on the moisture content, almost any value of soil resistivity could be measured and thus indicate the presence of a corrosive or non-corrosive soil.

All soils tested were found to have a minimum resistivity which was obtained at the optimum moisture content. Therefore, it is considered that a minimum resistivity is a common denominator and a basic characteristic of soils.

TABLE 1-Relative Soil Corrosivity\*

	ACID SOILS		ALKA SOI	
	Pit Depth	New Test	Pit Depth	New Test
Correlation coefficient Standard error	0.552	0.579	0.913	0.720
of estimate	11.8	12.0	4.6	7.8
Level of signifi- cance Number of	0.001	0.001	0.001	0.001
samples	50	50	39	39

\* Data obtained from reference 12. Soil corrosivity first determined by weight loss of steel; chart shows accuracy in duplicating corrosivity by pit depth and new test.

#### New Test Accuracy

Utilizing the pH and the resistivity values reported by the NBS<sup>12</sup> in their nation-wide tests, the relative soil corrosivity that was determined by this new test method was compared to the soil corrosivity determined by the reported weight loss of the steel specimens. The mathematical comparison was calculated by the method of least squares and the results are shown in Table 1.

In Table 1 it will be noted that in acid soils the accuracy of this new test method for predicting soil corrosivity closely duplicates that which could be obtained by using the pit depth measurements. For the purpose of mathematical comparison, the standard measure of soil corrosivity is assumed to be represented by the weight loss measurements.

In alkaline soils the approximation of relative soil corrosivity by using pit depth measurements is more accurate than this new test method. However, the results of the analysis shown on Table 1 indicates that the new test method is sufficiently accurate as a practical means for estimating relative corrosivity.

Based upon the statistical correlation of the test method with the reported results of exposing steel in 89 different soils throughout the United States by the National Bureau of Standards, it is apparent that this new test is a reasonable overall indicator of relative soil corrosivity.

#### Comparison of Test Methods— Underground

Soil corrosivity is generally evaluated in terms of the corrosion rate of buried steel. The more rapidly the steel corrodes the greater the reported soil corrosivity. The corrosion of steel buried in soils is generally reported in terms of two types of attack, these being (1) a general weight loss per unit of surface area, and (2) pitting or penetration in units of depth. Since both types of attack are the result of corrosion, each is a definition of soil corrosivity.

The relative corrosivities of soils which were determined by weight loss of steel were compared with those obtained by pit depth (Table 1). It will be observed that there is incomplete agreement when one criterion alone is used for expressing soil corrosivity.

The accuracy in determining soil corrosion as reported in nationwide tests, 12 either by pit depth or weight loss, was calculated by the method of least squares. 19

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TABLE 2—Comparison of Test Methods\*

	Shep- ard Resist.	Resist. Moist. Equiv.	Total Acidity	Mod- ified Colum- bia Rod	Putman Test	Nipple & Can	Denison Cell
Correlation coefficient	0.636	0.531	0.049	0.678	0.566	0.734	0.846
Standard error of estimate Level of significance Number of samples	2.66 0.026 12	2.93 0.077 12	3.45 Not 12	2.54 0.016 12	2.84 0.043 12	$\begin{array}{c} 2.34 \\ 0.006 \\ 12 \end{array}$	< 1.84 < 0.001 12

<sup>\*</sup> Data obtained from Table 100 reference 12.

\* Data obtained from Table 100 reference 12.

The results are shown in Table 1. The statistical significance of the relationship is shown by the correlation coefficient. As the correlation coefficient approaches 1.0, the statistical significance of the correlation increases.

With any number of samples there is a chance that the correlation may be accidental. Therefore, entered in Table 1 is a column with a legend titled "level of significance." Generally, a statistical correlation is considered to be reliable when the level of significance is less than 0.05 (or one chance in twenty) that the correlation is accidental. A statistical table, 19 shows that with a level of significance of 0.001 for the 50 samples shown on Table 1, the probability of obtaining a correlation coefficient of 0.552 as a result of pure chance would be 1 in one thousand or 0.001.

Tables 1, 2 and 3 list the standard error of estimate which represents the standard error of the data from the regression line. The smaller the standard error of estimate the less the scatter of the plotted data.

Comparison of Other Test Methods

In 1939 K. H. Logan and E. A. Koenig published data that compared the relative accuracy of seven different test methods which correlated a measured characteristic of soils to their relative corrosive effect on steel pipe. They concluded that the Denison Cell<sup>8</sup> was the most accurate of the available test methods.

The author applied a statistical analysis to the published data of Logan and Koenig by the method of least squares, as shown in Table 2. This analysis confirms conclusions that the Denison Cell was the most accurate test. As insufficient data were available, the accuracy of the new test method was indirectly compared to the data reported by Logan and Koenig.<sup>10</sup>

Table 98 of the NBS Circular 57912 gives data whereby the accuracy of this new test method can be compared to the reported accuracy of the Denison Cells employed at the NBS Laboratory and at the Waterways Experiment Station, Corps of Engineers, U. S. Army. The correlations between the accuracy of this new test method and the Denison Cell in the ranking of relative soil corrosivity in shown in Table 3. The actual soil corrosivity was assumed to be represented by the maximum pit depth found on steel specimens exposed for about 10 years. Pit depth was used as a criterion of the actual soil corrosivity as it was the basis used by Logan and Koenig. 10

Table 3 shows the results of this statis-

TABLE 3—Comparison of Test Methods\*

	Denisor	Denison Cell At:					
	NBS	Water- ways Exp. Sta.	Resist. @ 60 F	New Test	Denison Cell Avg. 15 Soils	Resist. @ 60 F	New Test
Correlation coefficient Standard error of	0.750	0.684	0.400	0.834	0.557	0.561	0.857
estimateLevel of significance Number of samples	1.71 0.02 9	1.88 0.042 9	2.37 Not 9	1.42 0.005 9	3.59 0.031 15	3.57 0.030 15	< 2.23 < 0.001 15

<sup>\*</sup> Data obtained from Table 98 reference 12.

tical analysis of the test results obtained by the NBS and the Waterways Experiment Station for 9 soils which were tested in the Denison Cell at both test facilities. The given soil data were analyzed by this new test method for accuracy and are also tabulated on Table 3. In Table 3 the "averaged results" of the Denison Cell are the average test values obtained from the NBS Laboratory and from the Waterways Experimental Station for all 15 soils. These values are compared with the results obtained by the use of this new test method.

The results of the statistical analysis shown on Table 3 indicate that this new test method has a greater accuracy in determining relative soil corrosivity than the Denison Electrolytic Cell. This conclusion is verified by comparing the results of the statistical analysis for the two test methods that are shown in Tables 2 and 3. Therefore, by comparing the available data, this new empirical test method appears to be a better indicator of relative soil corrosivity than previously recommended techniques.

Table 3 also lists the results of the statistical analysis which determined the accuracy in estimating relative soil corrosivity by means of the reported soil resistivities at 60 F.-It is of interest to note that for the 9 soils in which the Denison Cell was utilized to estimate soil corrosivity at the NBS Laboratory and the Waterways Experiment Station, the criterion of resistivity at 60 F was not an indicator of relative soil corrosivity. On the other hand the criterion of resistivity at 60 F as shown in Table 3 is an indicator of relative corrosivity of the 15 soils. In fact the analysis indicated it was comparable to the Denison Cell in accuracy. Also, as shown in Table 2, the test of resistivity at moisture equivalent is a rough indicator of relative soil corrosivity and agrees with the analysis of the resistivity at 60 F for the 15 soils listed in Table 3.

#### Discussion

As with most test methods there will be discrepancies between the test results and the actual field data. Comparing this new test method with others seems to show the new test to be a reliable but not a perfect delineator of relative corrosivity in all of the soils that were analyzed. In specific geographical areas it is anticipated that improved correlations may develop between results of this test method and field experience. Conversely, it is also expected that there may be some geographical areas where

the combined influence of the pH and resistivity may be outweighed by other variables. However, discrepancies or correlations between field data and this test method may give the various investigators a new approach to their investigations of the corrosion of buried metals.

The curves shown in Figure 1 correlating pH and resistivity to the anticipated corrosion rate are unquestionably subject to future refinements. Experience and additional tests will dictate those changes, as considerable interpolation and extrapolation of the original data were required to establish the initial shapes and contours of the curves. But despite its semi-preliminary nature, the existing degree of correlation between this new test method and the reported field data warrants the use of the existing chart in its present configuration.

Attempts were made to correlate this test method with published data relating to the internal corrosion of water mains. A correlation was not obtained. In the future it may be possible to relate this test method to such internal corrosion of water mains, tanks, etc., if one can evaluate the oxygen content or other primary variable of the water. However, this is pure speculation as no serious work in this field has been undertaken by the author.

#### Summary

The new test method discussed herein originally was derived from an investigation of the rate of corrosion of several thousand metal highway culverts in California. It has been correlated with the results of extensive underground corrosion studies published by the NBS. The graphic chart that correlates pH and resistivity to the rate of corrosion of iron is empirical and is derived from the original culvert corrosion rate data. In effect, the new test method combines and weighs the relative influence of both soil resistivity and pH on the corrosion rate of the buried steel samples.

Originally this new test method utilized the minimum resistivity value of a soil solution that was obtained by varying the moisture content. In contrast, the NBS data are based upon a soil being saturated with moisture, with all measurements made or corrected to a temperature of 60 F. It has been assumed that the minimum soil resistivity and the resistivity obtained at saturation are nearly equal in value. Experience indicates that a number of cases the minimum soil resistivity does not occur at the saturation point. On the basis of

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practical experience, it is suggested that greater weight be given to the minimum resistivity value in lieu of the NBS saturated soil criteria,

Based upon available data and comparing the relative accuracy of the various test methods, the proposed test method is a more reliable indicator of relative soil corrosivity than other investigated methods.

Inasmuch as the corrosion rates indicated in this test method are based upon the reported results of small samples of steel buried in the various soils, it is not likely that these values can be used to accurately predict conditions existing for long pipe lines. This is because of the possibility that the corrosion rate of such lines can be accelerated or reduced as a result of the formation of large scale corrosion cells.

The use of this new test method permits a rapid evaluation and prior knowledge of the relative corrosivity of soils in new locations. Engineering-wise, this knowledge permits improved confidence in the economic evaluations of the conditions to be met and the protective methods to be employed to extend the service life of ferrous materials or pipe systems imbedded in the soil.

#### Acknowledgments

This investigation which resulted in the development of a test method for estimating the corrosion rate of underground pipe and highway culverts was conducted as one of the activities of the Materials and Research Department of the California Division of Highways. The author wishes to express his appreciation to F. N. Hveem, Materials and Research Engineer, and J. L. Beaton, Supervising Highway Engineer, for their advice and direction during this study, and to Mr. W. E. Haskell, Associate Materials and Research Engineer, for his advice on the statistical analysis of the data. He also thanks the numerous personnel of the California Division of Highways and those of the Materials and Research Department who extended their aid and cooperation during this study.

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Any discussion of this article not published above will appear in December, 1961 issue.

## Cavitation Erosion of Structural Materials and Coatings\*

By J. Z. LICHTMAN, D. H. KALLAS, C. K. CHATTEN and CDR. E. P. COCHRAN, JR.

#### Introduction

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DESPITE CONTINUED improvement in hydrodynamic design and materials development, erosion of materials in cavitating environments is still an important problem. Hydrodynamic systems either with internal flow as characterized by pipes and pumps or with external flow such as flow around a ship's rudder may be subjected to cavitation. When, in a rapidly moving fluid, an increase in velocity or a drop in pressure of sufficient magnitude occurs, a vapor cavity is formed. The cavity may take the form of a small bubble or many bubbles or it may be a large steady void called fixed cavitation.1 In either case these bubbles or voids are transported downstream to collapse in a high pressure region. Those collapsing on or near the boundary produce high energy blows on the surface.2

The magnitude of these pressures has been reported at various values from several thousands of atmospheres3 to several thousand psi.2 Regardless of the differences of opinion concerning the magnitude of these forces, the physical damage caused is indisputable.4,5,6,7,8,9 Corrosion is also involved, especially in cavitation attack occurring in sea water.4 Considerable work in this field has been reported.10, 11

Regardless of the mode of attackmechanical or chemical-cavitation damage to the surface may be materially reduced or prevented by the use of an appropriate coating or suitable high strength structural material. Anti-corrosive coatings have been applied to U. S. Navy ships for many years with general success. These coatings have been applied to struts, rudders, sonar domes, sea chests and other appendages on ships in the 25 knot speed range. A new generation of navy ships, in a higher speed range intensify the need for reliable cavitationresistant coatings while the advent of military and commercial hydrofoil craft<sup>12,13</sup> in the 45-80 knot range imposes even more extreme conditions. The relation of the rate of erosion damage to fluid velocity is not completely understood but it has been estimated that the damage rate increases as the 6th power of the velocity.1 Careful design can minimize cavitation but it is apparent that general operating conditions at these higher speeds require superior coating systems or structural materials.

In view of the above problems, this investigation was directed principally toward the development of suitable cavitation erosion resistant structural mate-









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rials and coatings. This paper describes studies of:

a. The cavitation erosion resistance of structural materials and coatings.

b. The relationship between cavitation erosion resistance and other properties of materials.

c. The cavitation erosion phenomenon, particularly as related to the rotating disk cavitation apparatus.

#### **Experimental Procedure**

Rotating-Disk Apparatus

The rotating-disk apparatus used consists essentially of a test chamber in which a 12 inch diameter by approximately 1/8 inch thick specimen disk may be rotated in water under controlled conditions of fluid pressure and disk rota-tional speed. As illustrated in Figures 1 and 2 the principal features of the equipment are the test chamber with a removable chamber cover, a bearing assembly to house the drive shaft and a 30 HP variable speed motor drive.

A cross-sectional sketch of the chamber and drive assembly showing a disk mounted on the drive shaft and centrally positioned between the front and rear stilling vane sections is given in Figure 3. The purpose of the stilling vanes is to minimize rotation of the body of water within the chamber. Fresh water was used in all tests reported in this article; the water is piped into the chamber and C. K. CHATTEN has been chief of the Elastomers Development Section, Materials Development Branch of the Naval Material Laboratory since 1941. Prior to that, begin-ning in 1932, he was engaged in product development work in the rubber industry. He has a BS in chemistry from Drury College, Springfield, Missouri.

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#### Abstract

Abstract

The cavitation erosion resistance of a number of metallic and plastic structural materials and inorganic and organic coatings were determined in tests with a rotating disk cavitation apparatus. Relationships between cavitation erosion resistance and other properties were studied in order to develop materials having optimum cavitation erosion resistance. In general, high hardness structural metallic materials, high hardness structural metallic materials, high hardness metallic coatings and high tensile strength elastomeric coatings showed superior cavitation erosion resistance.

To clarify the mechanism of cavitation

perior cavitation erosion resistance.

To clarify the mechanism of cavitation erosion of a guiding surface moving relative to a fluid, studies of a disk specimen rotating in a fluid medium were made using high speed cinematography. Photographs were taken at 7,000 frames per second with a disk shaft speed of 3,200 rpm. The cavitation source hole was located at 5,36 inches radius, corresponding to 150 fps linear velocity. Cavitation clouds trailing from the source were found to form and collapse cyclically at a rate of 2,300 cps. Other cloud characteristics are also described.

leaves through a drain at the lower end of the chamber. Water pressure within the chamber is regulated by opening the inlet valve to full line pressure and adjusting the outlet valve as required. No attempt is made to control either the air content or the temperature of the water supply to the rotating-disk apparatus as this would have required the installation of a large stilling tank and a temperature regulating system.

<sup>★</sup> Submitted for publication January 27, 1961. A paper presented at the 17th Annual Conference, National Association of Corrosion Engineers, Buffalo, New York, March 13-17, 1961.

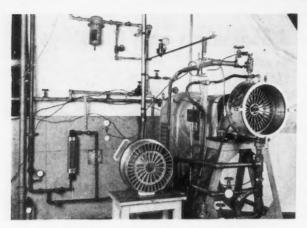


Figure 1—Over-all view of rotating-disk apparatus.

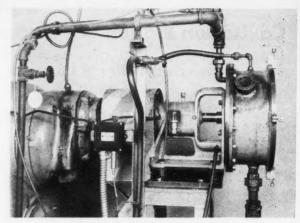


Figure 2—Side view of rotating-disk apparatus.

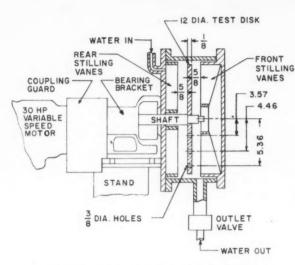


Figure 3-Position of disk in test chamber of rotating-disk apparatus.

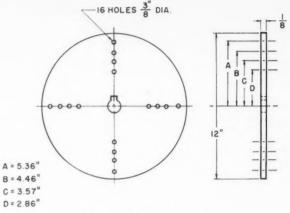


Figure 4—Test disk details and hole location.

Operating Conditions

Standard conditions for operating the rotating-disk apparatus were as follows:

Test Disk. The disk measures 12 inches in diameter by ½ inch thick as shown in Figure 4. The purpose of the ¾ inch diameter holes in the disk is to provide a source of cavity formation in the fluid medium. Three types of disks were used in this work for testing either bare metals or plastics, coatings or inserts (see Figure 5).

**Disk Velocity.** The disk is rotated in the water-filled chamber at 3200 rpm to produce linear peripheral velocities of 80, 100, 125 and 150 fps at hole radial locations of 2.86, 3.57, 4.46 and 5.36 inches, respectively.

Water Pressure. Water pressure within the chamber is maintained at 15 psig by adjusting the outlet pressure regulator. Under these conditions, water flow rate through the chamber is about 3.5 gpm.

Water Temperature. In at about 60 F and out at about 90 F (due to rotating-disk energy dissipation).

Test Period. The duration of the test period ranged from 6 min to 72 hrs as determined by the erosion resistance of the test materials. When the rotating-disk apparatus is operated as described above, the cavities formed in the water collapse within 1 inch downstream from the hole located at 5.36 inch radius.

#### Measurement Method

Eroded Material. Several methods of measuring volume loss of eroded disk or coating material were used including gravimetric measurements of various putty-like filler materials that were faired into the eroded cavity. These methods, which were based on the use of solid filler materials, have been superceded by one which is simpler to carry out and has higher precision and accuracy. This latter method consists of measurement of the volume of a fluid required to fill the eroded cavity level with the surface of the specimen disk.

The equipment set-up is illustrated in Figure 6. It consists of an adjustable stand for supporting the sample disk, a

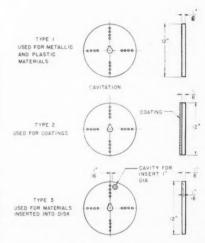


Figure 5-Test disk types.

surface gage adjusted to just contact the disk surface adjacent to the eroded region and a Rehberg 0.225 ml capacity microburette graduated to 0.001 ml  $(1\mu 1)$  for dispensing silicone oil into the eroded disk cavity. The silicone oil is Dow Corning 200 fluid, 200 cs viscosity;

it is discharged from the burette by mercury. The silicone oil is introduced into the eroded region from the burette to a level fill as judged by point contact between the surface gage and the oil fill. This test is repeated three times and the average volume of dispensed oil is taken as the volume of the eroded region.

Mechanical Properties. The mechanical properties of the various coating materials studied were determined by standard methods.<sup>14</sup> The properties measured included tensile strength, ultimate elongation, tear strength, volume swell, brittleness and bond strength to metal.

Since the data obtained during the course of the tests indicated that hardness of the plastic and elastomeric coatings might bear some relationship to erosion resistance, a more detailed hardness study was made of the several coating materials. For this purpose a hardness indentation instrument conforming to Federal Method 3051 was adapted for use with both a 1/32 and a ½ inch diameter spherical indentor foot. Hardness readings were taken 60 seconds after applying the major load and recovery readings were made 60 seconds after removing the major load.

#### Test Materials

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ed ity ml he is A number of metallic, plastic and coating materials were investigated in the rotating disk apparatus and are listed in Table 1.

Several mechanical properties of the metallic materials enumerated above are listed in Table 2. These data have been obtained from Material Laboratory tests, manufacturers' bulletins and standard reference handbooks.

The mechanical properties of the structural plastic and coating materials are listed in Table 3.

High Speed Photography
High speed motion pictures were taken in order to study the formation and collapse of the cavitation clouds in the rotating-disk machine.

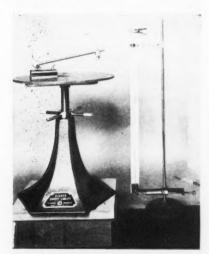


Figure 6—Microburet apparatus for measuring cavitation damage to test specimens.

Photographic Equipment. Pictures were taken using a Wollensak Fastax camera, Model 16 mm W163269. Cine-Kodak Tri-X, 16 mm TXR 430 film was used. Illumination was provided by four 750 watt photographic lamps directed toward the transparent plastic chamber cover of the apparatus and the 134 inch diameter glass-covered aperture in the side of the chamber, shown in Figure 2.

Photographic Procedure. Pictures were taken at a disk speed of 3200 rpm, at 15 psig chamber pressure, and at 3.5 gpm water flow rate. These pictures were taken from the front of the chamber so

that the top of the cloud is observed and from the side so that the face of the disk appears as a straight line and the cloud can be seen impinging on the face of the disk.

#### Results

Erosion Resistance of Materials

Data showing the average erosion rates of the materials occurring at the 150 fps positions on the respective disks and photographs of typical erosion damage of the materials are given in Table 4. Where a material was severely damaged (e.g., the erosion of aluminum 1100-0 after 3½ hours or the extensive perforation of coatings in less than 24 hours), only a

TABLE 1-Materials and Cavitation Disk Type

Material Type	Description	Disk Identification Code	Cavitation Disk Type	Coating Thickness Mils
Structural Metallic	Monel CRA. Monel CRS Monel Cast H	BH BF DX	1 (See Figure 5)	
	Stellite 6B	FC FD FC FD	3 " 3 " 3 "	*****
	Mild steel SAE 1016 Mild steel SAE 1030 Mn-Ni bronze Ni-Al bronze	AR AJ AG	1 " 1 " 1 " 1 "	
	Mn bronze. Comm brass. Aluminum 1100-0.	AH F. AV T. U	1 "	*****
Structural Plastic	Polyvinyl chloride	K, L R, X FG	1 " 1 " 3 "	63
Coatings	Ceramic (flame sprayed) Al-titania. Al-alumina.	EJ EL	2 ::	27 25
	Glass (fused) Dense borosilicate Borosilicate.	DZ DY	2 ".	18—16 19—24
	Metallic (flame-sprayed) Ni Cr alloy, fused Bronze, Ni, unfused	EK EM	2 ".	20 27
	Elastomeric Liquid neoprene. Liquid neoprene. Polysulfide (faulking type). Polysulfide (flame sprayed). Polysulfoxane (rm temp vulc). Polyurethane (cast). Neoprene (press bonded).	CQ CJ J CR CH BC	2 " 2 " 2 " 3 " 3 "	22-30 30-50 30-40 60 60 82
	Plastic Epoxy (enamel) Epoxy (paste). Teflon sheet Nylon (fluidized bed)	BZ CN AO ED	2 " 3 " 2 " 2 "	15 60 30 25
	Silicate Zinc-rich silicate	ET	2 "	35

TABLE 2—Mechanical Properties of Metals

	Ultimate	Yield	P1	Hardness		Endurance Limit.	Izod, Impact
Material	Strength, psi	Strength, psi	Elong., Percent	Rockwell	Brineil*	psi	ft-lbs
Monel CRA Monel CRS Monel Cast H Stellite 6B	80,000 80,200 100,000 min 165,000	35,000 34,500 65,000 min 111,000	42 32 10 5	B74 B71 C37 C43	124 122 348 405	25,000 25,000	90-120 75-115 35-45
Stainless steel, Type 304 Mild steel, SAE 1016 Mild steel, SAE 1030	80,000 min 74,000 85,000	30,000 min 62,000 72,000	50 24 26	B90 B85	184 162	42,000	90-120
Mn-Ni bronze	75–83,000	35-40,000	18-30	B78	145		
Ni-Al bronze Mn bronze Comm brass Aluminum 1100-0.	85–95,000 65–75,000 61,000 13,000	32-47,000 25-30,000 50,000 5,000	15-25 25-30 6 40	B82 B71 B62 B35	150 122 105 80	5,000	

<sup>\*300</sup> Kg, 10 mm steel ball.

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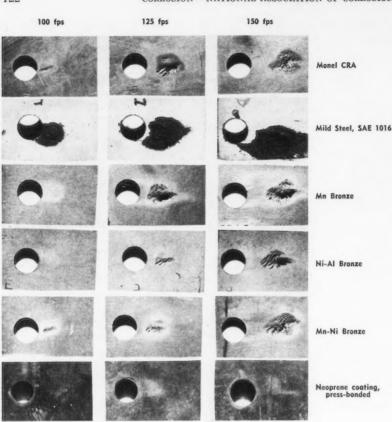


Figure 7—Effect of hole viscosity on eroded volume of selected materials at various velocities. Exposure time: 72 hours.

qualitative description (gross failure) is indicated.

Most of the coating materials tested during the course of this program and which failed primarily as a result of adhesion deficiencies are not included in this paper. The polysulfide (caulking type) elastomeric coating has been included to illustrate this type of deficiency. The fact that a material exhibited insufficient bond strength to adhere to the metal disk under cavitating conditions was considered to be sufficient proof of its inadequacy as a protective coating.

#### Effects of Relative Fluid Velocity

The dependence of erosion rate on the relative velocity at the different disk holes is illustrated in Figure 7. The increase in erosion rate with increase in velocity is typical of the behavior of all the materials studied and confirms conclusions given by Knapp¹ and the authors⁴ that cavitation erosion increases exponentially with velocity. Below a threshold of velocity of approximately 80 fps (50 knots), cavitation erosion is negligible.

#### Effect of Time of Exposure

The effect of time of exposure of materials to cavitating conditions at different velocities is indicated graphically in Figure 8. All materials showed an increase in total erosion with time, the erosion rates varying with type of material, particularly at higher disk speeds.

#### Cavitation Cloud Studies

The high speed cine photos were taken with a test disk rotating speed of 3200 rpm, 15 psig chamber pressure, 3.5 gpm water flow rate through chamber, and hole velocity 150 fps. A black painted steel reinforced aluminum disk was used.

#### TABLE 3—Mechanical Properties of Structural Plastic and Coating Materials

						Hardness Indentation, 0.01 mm			
		Tensile Strength.	Ultimate Elong.,	Tear Str.,	Rockwell Hardness	Part 1/32" Indenter	1/8" Is	ndenter	
	Material	psi psi	Percent	ppi		Loaded	Unloaded	Loaded	Unloaded
Structural Plastics	Polyvinyl chloride. Styrene-acrylonitrile. Nylon (molded sheet) 0.2% water content. 2.5% water content.	6- 9000 10-12000 11500 11000	1-5 1.0-3.2 60 300	***	R110-120 M30-55 M79 M59	4.2	1.0	3.0	0.3
Coatings	Ceramic (flame-sprayed); Al-Titania. Al-Alumina	******		***		6.0	2.1	1.2	0.5
	Glass (fused): Dense borosilicate glass Borosilicate glass								
	Metallic (flame-sprayed): Ni-Cr Alloy, fused. Bronze, Ni unfused.				C58-62 B50	1.3 2.7	0 0.9	1.2 2.5	0.2 1.1
	Elastomeric: Liquid neoprene Polysulfide (caulking type) Polysulfide (flame-sprayed) Polysulfide (flame-sprayed) Polyurethane (cast) Neoprene (press bond)	1890 120 390 5300 1590	860 1030  90 600 410	160 12  8 310 25		43 27 40	17 11 4	10 97 6 51 18 55	1.8 68 1.2 8 1.0 3.5
	Plastic: Epoxy (enamel) Epoxy (pa-te) Treflon. Nylon (fluidized bed)	1810 3050 3200	<10 <10 290	20 120		$\begin{array}{c} 4.4 \\ 5 \\ 30 \\ 4.5 \end{array}$	1.0 2.1 11 1.9	1.0 2.0 2.5 2.3	0.4 1.0 0.9 0.2
	Silicate: Zinc-rich silicate	****				4	2.5	4	1.0

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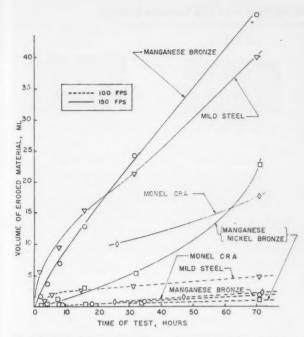


Figure 8—Effect of time of exposure on eroded volume of various materials at 100 and 150 fps.

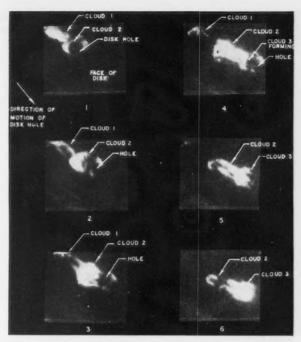


Figure 9—High speed motion pictures taken through the front of the rotatingdisk apparatus. Shaft speed: 3200 rpm.

The frame sequence shown in Figure 9 was selected from the film taken from the front of the chamber and shows the disk hole and the formation and collapse of several clouds.

A schematic representation of the face of the disk, the cavitation inducing hole in the disk and the associated cavitation clouds on the downstream side of the hole is shown in Figure 10 to facilitate interpretation of the high speed motion picture sequences.

The frame sequence shown in Figure 11 was selected from a film taken from the side (toward the edge of the disk) and shows the formation and collapse of several clouds on the face of the disk.

A schematic representation of the edge of the disk and the associated cavitation clouds forming and collapsing on the downstream side of the hole (not seen in edge views) is shown in Figure 12 to facilitate interpretation of the high speed motion picture sequences.

Several characteristics regarding the growth and collapse of cavitation clouds at 15 psig and 150 fps can be determined from the high speed motion pictures. These are summarized in Table 5.

#### Discussion and Conclusions

#### Material Performance

The cavitation erosion resistance of a number of materials has been determined with the rotating-disk apparatus. A rating of the erosion resistance of these materials at 150 fps is given in Table 6.

The following conclusions are made regarding the cavitation erosion resistance of the different types of materials evaluated in this paper:

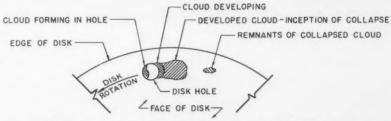


Figure 10—Schematic representation of face of disk showing stages of cavitation cloud development and collapse.

#### Structural Metals

1. Although no direct relationship between erosion resistance and hardness of metals could be established, a review of Table 7 wherein metals are shown in order of decreasing hardness indicates that for a very hard material, such as Stellite 6B the erosion resistance is high while for a very soft material such as Aluminum 1100-0 the erosion resistance is love.

2. Similarly, no direct relationship between erosion resistance and mechanical properties of metals could be established. A review of Table 8 wherein metals are shown in order of decreasing ultimate strength indicates that for a very high strength material such as Stellite 6B the erosion resistance is high while for very low strength material such as Aluminum 1100-0 the erosion resistance is low.

#### Structural Plastics

The ultimate elongation of the plastics appears to be significant in determining their erosion resistance. For example, molded nylon having a water content of 2.5 percent has a reported ultimate elon-

gation of 300 percent. This material exhibits high erosion resistance in comparison with plastics having substantially lower ultimate elongation.

#### Coating

1. Fused glass and fused high hardness Ni Cr flame-sprayed alloy coatings have high erosion resistance.

Unfused ceramic and unfused flamesprayed metallic coatings have low erosion resistance.

 Elastomeric coatings of high tensile strength, ultimate elongation, and high tear strength show high erosion resistance.

4. Plastic coatings having low tensile strength (less than 5000 psi), high hysteresis and low ultimate elongation (less than 300 percent) have low erosion resistance.

5. A hard, brittle zinc-rich silicate coating having considerable indentation hysteresis (plastic deformation) exhibits low erosion resistance.

#### Environmental Factors

In respect to materials, generally, the following conclusions may be made con-

#### TABLE 4—Results of Rotating-Disk Tests in Tap Water at 150 fps Hole Velocity

Monel CRA



Time tested: 72 hrs Erosion rate: 0.3 µl/hr, avg

Stainless Type 304



Time tested: 24 hrs Erosion rate: 0.4 µl/hr, avg

Monel CRS



Time tested: 72 hrs Erosion rate: 0.6 µl/hr, avg

Mild Steel, SAE 1016



Time tested: 72 hrs Erosion rate: 0.7 µl/hr, avg

Monel, Cast H



Time tested: 33 hrs Erosion rate: 1.0 μl/hr, avg



Time tested: 48 hrs Erosion rate: 1.3 μ1/hr, avg

Time tested: 72 hrs Erosion rate: 0.3 µl/hr, ava

Stellite 6B

Time tested: 24 hrs Erosion rate: 0.03 µl/hr, avg

Mn-Ni Bronze

Ni-Al Bronze



Time tested: 72 hrs Erosion rate: 0.4 µ1/hr, avg

Mn Bronze



Time tested: 72 hrs Erosion rate: 0.6 µI/hr, avg

Commercial Brass



Time tested: 72 hrs Erosion rate: 0.9 µl/hr, avg



Time tested: 0.1 hr Erosion rate: 24  $\mu$ l/hr, avg 3½ hrs—gross damage

Polyvinyl Chloride



Time tested: 3 hrs Erosion rate: 7 μl/hr, avg

Styrene-acrylonitrile



Time tested: 1 hr Erosion rate: 32 µl/hr, avg

Nylon (molded sheet)



Time tested: 24 hrs Erosion rate: 0.1 µl/hr, avg

Ceramic (flame sprayed) Al-Titania



Time tested: 5 hrs Gross failure

#### TABLE 5—Cavitation Cloud Characteristics

Characteristic	Value
Time for initiation and maximum growth of cloud Time between initiation of	0.00043 sec, avg
Cloud collapse time	0.00043 sec, avg 0.00014 sec, avg
Maximum cloud length	5% inch 3% inch

cerning the significance of some environmental factors.

Relative Fluid Velocity. The erosion rate increases with increase in velocity above a threshold velocity of approximately 80 fps. Below this threshold velocity cavitation erosion is negligible.

Time of Exposure. The erosion rate is approximately constant with time, particularly at the lower velocities of test. No incubation period is indicated. Cavitation Cloud Studies

The high speed motion pictures indicated that the cavitation cloud formation in the rotating-disk apparatus is of a cyclic nature. Investigations reported by Knapp¹ and Vennard¹⁵ using water tunnels, have also shown the cyclic nature (formation and collapse) of the cavitation cloud. Knapp used an ogival specimen having a hemispherical nose and mounted on a support sting while Vennard described the use of a Venturi in a tunnel to obtain the cavitating regions being studied. Knapp indicated that "the strong cyclic behavior with nearly complete filling of the cavity on each cycle seems to be associated with the higher velocities, i.e., from 50 fps up."

The cycle time value determined in the present experiments is lower than those reported by Knapp who determined cycle times from 0.0050 to 0.0198 sec with cavities varying in length from 1.0 to 3.6 inches at fluid velocities varying from 100 to 59 fps. Knapp found that the cycle time increased with increase in length of the cloud and with decrease in relative fluid velocity. The cycle time data obtained in the present studies at 3200 rpm appear to be of the same order as the Knapp data as related to fluid velocity and cavity length.

The part of the disk including the downstream half of a hole appears to act as if it were the leading edge of a bluntnosed foil. The upstream half of the hole appears to act as if it were the trailing edge of a blunt-ended foil. Thus cavities develop directly from the edges of the leading surfaces and trail from the trailing surfaces.

Apparatus

The following conclusions are made regarding the capabilities of the rotatingdisk apparatus.

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#### **TABLE 4 (Continued)**

Ceramic (fused) Metallic (flame sprayed) Ni-Cr alloy, fused Borosilicate Glass Al-Alumina ense borosilicate alass Time tested: 24 hrs Erosion rate: 0.05 µl/hr, avg Time tested: 72 hrs Erosion rate: 0.03 µl/hr, ava Metallic (flame sprayed) Bronze, Ni (unfused) Liquid neoprene Polysulfide (caulking type) Polysulfide (flame-sprayed) Time tested: 3/4 hr Gross failure (adhesion separation in addition to cavitation erosion) Time tested: 24 hrs Gross failure Time tested: 46 hrs Slight scuffing of coating Time tested: 5 hrs Gross failure Plastic Polysiloxane (room temp vulc) Polyurethane (cast) Neoprene (press bonded) Epoxy (enamel) Time tested: 7 hrs Gross failure Time tested: 72 hrs Slight scuffing Time tested: 72 hrs Slight scuffing Time tested: 1 hr Gross failure Silicate Zinc-rich silicate Nylon (fluidized bed) Epoxy (paste) Teflon Time tested: 5 1/3 hrs Erosion rate: 10 µl/hr, avg Time tested: 18 hrs Gross failure Time tested: 0.75 hr Gross failure Time tested: 6 hrs Gross failure

- a. The apparatus discriminates between different structural and coating materials with respect to cavitation erosion resistance.
- b. The apparatus stimulates serviceencountered velocity flow conditions which contribute to hydrodynamic shear stresses acting on coating materials.
- c. The apparatus permits simultaneous study of one or more materials under a range of velocity conditions.
- d. The apparatus generates cyclic cavitation cloud formation similar to those of water tunnel apparatus.<sup>1, 15</sup>
- e. The apparatus produces cavitation erosion damage of materials similar in appearance to that occurring in service.

#### Future Work

Investigations will be carried out in several areas, as follows:

Corrosion and Chemical Reactivity. Erosion studies of metallic materials will be made in sea water to determine the significance of corrosion and chemical reactivity on damage as contrasted with cavitation erosion in a less corrosive environment such as fresh water.

High Pressure Effects. Investigations will be made at increasing pressures above those described in the present paper to determine the significance of this factor and its effects on the resistance of elastomeric materials. Although several elastomeric coatings have been found which are highly resistant at depths up to 30 ft of water (15 psig), at increasing pressures the rheological and dynamic properties of these materials may change and different coating systems may have to be developed.

Dynamic Properties of Materials. The behavior of plastic and elastomeric coat-

ing materials will be studied at varying rates of deformation up to 6 kc per sec to determine relationships between rheological and hysteresis properties and cavitation erosion resistance.

Apparatus Characteristics. There is much to be learned on the basic mechanism of cavitation erosion. Questions regarding the generation and collapse of cavities, the mechanism of collapse, the rate of collapse and the damage forces resulting require further study and investigation. The rotating-disk apparatus may lend itself to such fundamental studies. For example, the disk characteristics as they influence cavitation cloud characteristics should be studied. Factors such as disk thickness, hole size and hole profile have only been touched on to date. The apparatus characteristics including geometry of stilling vanes, air content, temperature and pressure of water

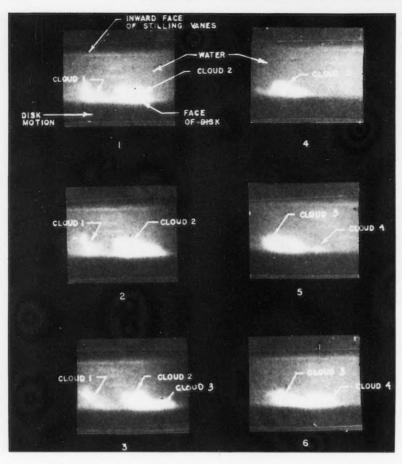


Figure 11—High speed motion pictures taken through side view port of rotating-disk apparatus. Shaft speed: 3200 rpm.

need considerable investigation. Much of this work should be examined with a view to comparison with other types of apparatus including a water tunnel,<sup>1</sup> magnetostriction apparatus<sup>5, 6, 7, 16</sup> and the spark gap apparatus of Naudé and Ellis.<sup>2</sup>

Stream Velocity. An important variable of the rotating-disk apparatus method, still to be defined precisely, is the relative velocity of the water with respect to the rotating-disk. This factor has been discussed earlier in this paper at which time it was pointed out that it has been assumed that the water in the chamber is not following the rotation of the disk but is entirely restrained by the stilling vanes. It is probable, however, that the water immediately adjacent to the disk face is being dragged around with the disk. Several experiments suggest themselves in order to calibrate the apparatus with respect to this stream velocity variable. The experiment which is most intriguing is the most direct one; it involves installing a flat ½ inch plate with a ¾ inch hole in a calibrated flow tunnel and observing the length and behavior of the cavity downstream from the hole as the stream flows over the face of the plate. This behavior can be compared directly against the rotating-disk performance and stream velocity can then be related to cavity size, shape or build-up and collapse rates.

Service Applications. Service applications will be made of those materials which have shown outstanding erosion resistance. In addition to achieving the basic objectives of this project, the protection of ships' structures subject to cavitation erosion environments, these service applications will afford an opportunity to confirm the Laboratory conclusions as to material performance and experimental procedures.

TABLE 6—Ratings of Materials by Cavitation Erosion Resistance

	Average Erosion Vol.		N	laterial
Rating	μl/hr	Metallic	Plastic	Coatings
1 0-0.2	1 0-0.2 Stellite 6B	Nylon (molded)	Dense borosilicate glass. Łoro- silicate glass. Ni-Cr alloy (flame-sprayed, fused), liquid neoprene, rolyurethane (cast) neoprene (press bonded)	
2	0.2-0.4	Monel CRA, Mn-Ni bronze		
3	0.4-0.6	Monel CRS, Stainless 304, Ni-Al bronze		
4	0.6-0.8	Steel, SAE 1016 Mn bronze		
5	0.8-1.0	Monel, Cast H, Comm brass		
6	Greater than 1.0	Steel, SAE 1030	PVC	Al-titania flame-sprayed
		Aluminum 1100-0	Styrene- acryloni- trile	Al-alumina flame-sprayed bronze-Ni flame-sprayed, unfused polysulfide (caulking type) polysulfide (flame- sprayed), polysiloxane (room temp vulc), epoxy enamel, epoxy (paste), Teflon sheet, nylon (fluidized bed), silicate, zinc rich

TABLE 7—Hardness and Erosion Characteristics of Alloys

Material	Rockwell	Brinell	Avg Erosion
	Hardness	Hardness	Rate, µl/hr
Stellite 6B. Monel, Cast H. Stainless, Type 304.	C43	405	0.03
	C37	348	1.0
	B90	184	0.4
Mild steel, SAE 1016	B85	162	0.7
Ni-Al bronze	B82	150	0.4
Mg-Ni bronze	B78	145	0.3
Monel CRA.	B74	124	0.3
Monel CRS	B71	122	0.6
Mn bronze	B71	122	0.6
Comm brass	B62	105	1.0
Aluminum 1100-0	B35	80	20.0

TABLE 8—Tensile Strength and Erosion Characteristics of Alloys

Material	Ultimate Tensile Strength, psi x 1000	Avg Erosion Rate, µl/hr
Stellite 6B	165	0.03
Monel, Cast H Ni-Al bronze	100 90	1.0 0.4
Mild steel, SAE 1030	85	1.3
Mn-Ni bronze	80	0.3
Monel CRA	80	0.3
Monel CRS	80	0.6
Stainless, Type 304	80	0.4
Mild steel, SAE 1016	74	0.7
Mn bronze	70	0.6
Comm brass	61	1.0
Aluminum 1100-0	13	20.0

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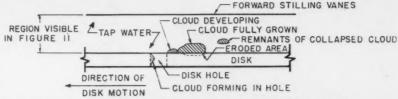


Figure 12—Schematic representation of edge of disk showing stages of cavitation cloud development and collapse.

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